DEC 2 3 1981

TD 8.2.C85/11/v.2

December 1980
Interim Report

DOT HS-805-822

US Department
of Transportation
**National Highway
Traffic Safety
Administration**

Crash Protection Systems for Handicapped School and Transit Bus Occupants

Volume II–Technical Report

Anil V. Khadikar
Eric Will

Minicars, Inc.
55 Depot Road
Goleta, CA 93117

Contract No. DOT HS-7-01774
Contract Amount $485,592

COMPLETED

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

306

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT-HS-805-822		

4. Title and Subtitle	5. Report Date
Crash Protection Systems for Handicapped School and Transit Bus Occupants Volume II - Technical Report	December 1980
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Anil V. Khadilkar and Eric Will	IR-1074-12-80
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Minicars, Inc. 55 Depot Road Goleta, CA 93117	11. Contract or Grant No. DOT-HS-7-01774
	13. Type of Report and Period Covered Interim Report September 1977- March 1980
12. Sponsoring Agency Name and Address U.S. Department of Transportation National Highway Traffic Safety Administration 400 Seventh Street, S.W. Washington, DC 20590	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A series of eight school and transit buses were subjected to nine frontal fixed barrier, two rear moving barrier and three side impact tests. Each test bus carried up to seven fully instrumented dummies – one in the driver seat, two in forward facing seats, two in side facing seats, and two in wheelchairs. The wheelchairs were secured and the wheelchair-seated dummies were restrained using commercially available restraint systems. The dummy locations, wheelchair securements, passenger restraints, crash modes and impact speeds were selected on the basis of a state-of-the-art survey and accident data analysis of operational practices and experiences with school and transit buses.

The report contains the results of the state-of-the-art survey, accident data analysis and the bus crash test program. Typical deceleration crash pulses for a wide range of school bus sizes and full size transit buses are presented, as are plots of dummy trajectories and records of dummy injury measures for the selected test conditions.

The report is presented in five volumes: Volume I, Executive Summary; Volume II, Technical Report; Volume III, Appendices A, B, C and D; Volume IV, Appendix E; and Volume V, Appendices F and G.

17. Key Words	18. Distribution Statement
Handicapped Transportation, Accessibility, Bus Crash Tests, Wheelchair Securements, Crash Protection, Deceleration Crash Pulses, School Bus, Transit Bus, Lifts, Ramps	Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	251	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

BLANK

PAGE

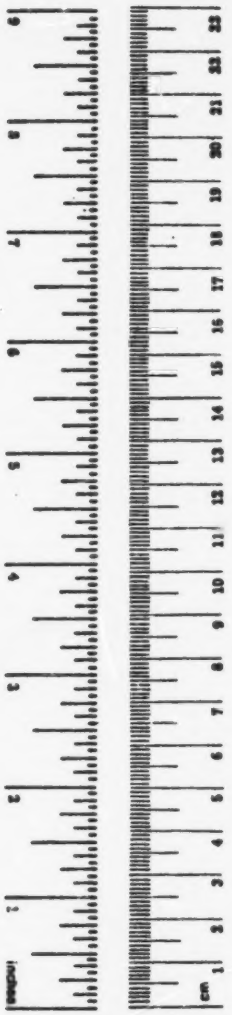
MICROFILMED FROM
BEST AVAILABLE COPY

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

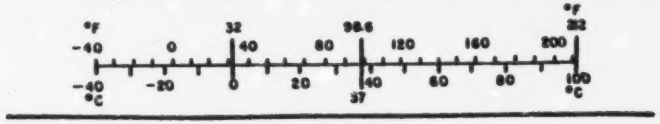
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ACKNOWLEDGEMENTS

The authors of this report gratefully acknowledge the technical guidance, support and encouragement provided by the NHTSA Contract Technical Managers, Messrs. H.R. Moody and W. Leasure, and the UMTA Contracting Officer's Technical Representative, Mrs. P. Simpich.

The nature of this program involved the collection of massive amounts of technical data, accident data and actual hardware. A number of people enthusiastically provided us valuable information and even hardware. All such contributions are greatly appreciated. The following organizations and their representatives deserve a special mention:

Organization	Representative
Aeroquip/Nelson-Dunn, Inc.	Mr. Ray Lee
State of California Department of Transportation	Mr. Carl Stewart Mr. Herb Reinl
California Association for Physically Handicapped (CAPH)	Ms. Julie Velarde
Carpenter Body Works, Inc.	Mr. Dick Verheul
Collins Industries, Inc.	Mr. Vic Wilhem
Crown Coach Corporation	Mr. Ray Hartman
Everest & Jennings	Mr. Keith Rodaway
National School Transportation Association (NSTA)	Mrs. Billie Reynolds
National Highway Traffic Safety Administration (NHTSA)	Mr. Martin Paliokas

BLANK PAGE

TABLE OF CONTENTS

SECTION	TITLE	PAGE
	INTRODUCTION	1
	Background	1
	Objectives	2
	Program Methodology	3
	OVERVIEW	5
1	STATE OF THE ART SURVEY	8
	1.1 Introduction	8
	1.2 Findings of the State of the Art Survey	9
	1.2.1 Manufacturers	9
	1.2.2 Trade Publications and Annual Statistics	49
	1.2.3 Other Independent Organizations and Groups	50
	1.2.4 Past and On-Going Government Agency Research Programs	55
	1.2.5 Personal Interviews	76
	1.3 Use of Bus Transportation by the Handicapped	80
	1.3.1 Demography of the Handicapped Population, Overall U.S. Population	80
	1.3.2 School Children Population	81
	1.4 Safety Standards	86
	1.4.1 NHTSA Regulations	86
	1.4.2 UMTA Regulations	87
	1.4.3 State and Local Regulations	88
	1.5 Conclusions	91
	1.5.1 Standards and Regulations - Crash Protection	91
	1.5.2 Transportation Needs of the Handicapped	91
	1.5.3 Desired Characteristics of Equipment	93

TABLE OF CONTENTS (cont'd)

SECTION	TITLE	PAGE
2	ACCIDENT, INJURY AND FATALITY DATA ANALYSIS.....	97
	2.1 Introduction.....	97
	2.2 Data Sources.....	100
	2.3 Findings of Data Search.....	101
	2.4 Collision Modes.....	112
	2.5 Summary of School Bus Survey Results.....	115
	2.6 Conclusions.....	119
	2.7 Design Guidelines.....	120
	2.8 Evaluation Criteria for Crash Protection Systems...	123
3	DECELERATION CRASH PULSE DEVELOPMENT.....	125
	3.1 Introduction.....	125
	3.2 School and Transit Bus Crash Test Program.....	128
	3.2.1 General Test Procedures Used.....	128
	3.2.2 Test Parameters.....	140
	3.2.3 Bus Crash Test Results.....	160
4	CONCLUSIONS AND RECOMMENDATIONS.....	219
	4.1 State-of-the-Art Survey.....	219
	4.2 Analysis of Injury and Fatality Data.....	226
	4.3 Development of Deceleration Crash Pulses.....	227
	4.4 Recommendations.....	229
5	FUTURE PLANS AND PROGRAM GOALS.....	231
	REFERENCES.....	233
	BIBLIOGRAPHY.....	238

TABLE OF CONTENTS (cont'd)

APPENDIX	TITLE	VOLUME
A	MANUFACTURERS AND ORGANIZATIONS CONTACTED.....	III
B	ANTHROPOMETRY OF SCHOOL BUS POPULATION DATA.....	III
C	ACCIDENT DATA CONTACTS AND SOURCES OF INFORMATION AND QUESTIONNAIRE USED BY NATIONAL SCHOOL TRANSPORTATION ASSOCIATION (NSTA) FOR THE MINISURVEY OF THEIR MEMBER ORGANIZATIONS.....	III
D	SIMPLIFIED DECELERATION CRASH PULSES AND SELECTED COMPUTER FILTERED CRASH PULSES FOR THE TEST BUSES.....	III
E	DYNAMIC SCIENCE, INC. TEST REPORTS.....	IV
F	CALSPAN CORPORATION TEST REPORTS 6440-V-1, 6440-V-2 AND 6440-V-3.....	V
G	CALSPAN CORPORATION TEST REPORTS 6440-V-4, 6440-V-5 AND 6440-V-6.....	V

INTRODUCTION

This is the Interim Report of the National Highway Traffic Safety Administration (NHTSA) program, "Crash Protection Systems for Handicapped School and Transit Bus Occupants" (Contract DOT-HS-7-01774). The NHTSA is one of the agencies of the U.S. Department of Transportation (DOT) sponsoring this program. The other agency that supported part of this work is the Urban Mass Transportation Administration (UMTA).

BACKGROUND

The background for this research program lies in the passing of the Federal Motor Vehicle Safety Standard (FMVSS) 222. This standard specifies padding requirements of seat backs and maximum spacing between the seats in school buses. The central idea behind these specifications is to contain the school bus occupants within their seating spaces and to allow them seat back padding protection and thereby control their trajectories during frontal impacts. In addition, FMVSS 222 disallowed any side facing or longitudinal seats on school buses. The elimination of side facing seats and the somewhat confined space between the forward facing seats resulted in some inconvenience for ambulatory handicapped school children. The ease of entry and egress to the seats was, they complained, substantially reduced. In response to those complaints, the NHTSA issued a waiver on side facing seats for those school buses that are in use exclusively for the transportation of handicapped school children. This facilitated the ingress and egress of the ambulatory handicapped children who had difficulty using the conventional FMVSS 222 seats. However, this raised the issue of crash protection available to occupants of side facing seats. In question as well, was the safety of wheelchair seated occupants who also had more surrounding space than FMVSS 222 maximum spacing allowed. These two issues are the background for the NHTSA's initiation of this research project. The UMTA then joined the project, and the contract scope was expanded to include transit buses and handicapped users of the transit buses.

OBJECTIVES

In keeping with the background of this research program, the specific objectives of the program have been established:

1. To identify and document lifts, ramps, tiedowns/securement systems and other ingress and egress hardware that has been used in the transportation of handicapped passengers – further, to critically evaluate the available hardware to assess its impact on the convenience and the safety of the handicapped occupant during operational and crash situations.

2. To compile, analyze and evaluate existing accident data involving handicapped occupants in order to ascertain specific causes of injuries and deaths; specifically, to identify the injury-causing hardware and injury-causing mechanisms.

3. To conduct a series of full-scale bus crash tests in order to obtain:

- Representative deceleration crash pulses for later sled tests
- Baseline performances for handicapped occupants (simulated by anthropomorphic dummies) using existing crash protection devices under selected impact test conditions

4. To conduct a series of sled tests that will experimentally establish the influence of various characteristics of crash protection systems on the effectiveness of available crash protection. The selected system parameters were

- Bus size
- Passenger size
- Wheelchair orientation
- Impact characteristics such as direction, speed
- Wheelchair securement type
- Passenger protection system (for example, belts and padding)
- Passengers in side facing seats.

PROGRAM METHODOLOGY

To meet the program objectives, the research started with a state-of-the-art survey of the equipment, practices and procedures used by operators of school and transit buses for the transportation of handicapped passengers. The results of the survey are reported in Section 1 of this Interim Report. The work was identified as Task 2 of the research program methodology.

Simultaneously with the state-of-the-art survey, available accident data were collected, analyzed and evaluated. The results of that effort are presented in Section 2 of this report. The accident data analysis was identified as Task 3 of the research program methodology.

Appendices A, B and C include the background data sources that were used in the state-of-the-art survey and in the analysis of injury and fatality data.

Section 3 of this report documents our efforts in a series of full-scale bus crash tests. Five school and three transit buses were subjected to a total of nine frontal impact tests into a fixed barrier, two rear and two side impact tests using a moving barrier, and one side impact test using a full size car. Each test bus had up to seven instrumented dummies, up to 72 channels of data, and up to 12 high-speed cameras recording each test. The results of the tests are summarized in Section 3, and all of the detailed test reports and some additional pulse data are presented in Appendices D, E, F and G.

The effort associated with full-scale bus crash tests was identified as Task 4 of the program methodology. Overall conclusions of Tasks 2, 3 and 4 are summarized in Section 4 of this report, which also makes a series of recommendations.

As of the writing of this report, Tasks 2, 3 and 4 of the program methodology are complete. Those three tasks are directly responsive to the first three specific objectives of this research program. The next step of this program will be a series of sled tests to investigate the influence of system parameters on crash protection. The details of that planned effort are outlined in Section 5 of this report.

It is appropriate to mention here that Task 2 (Section 1) and Task 3 (Section 2) of this program were able to determine the ground rules and baseline practices of the transportation of handicapped passengers. The equipment, seating locations, wheelchair orientations, and crash modes/speeds identified by the results of those tasks were used in defining the parameters for the full-scale bus crash tests. Thus the results of Task 4 (Section 3) reflect realistic transportation practices in use today.

The next section of this Interim Report provides an overview and can be used as a "road map" to the report.

OVERVIEW

The Interim Report is published in five volumes:

Volume I - Executive Summary
Volume II - Technical Report
Volumes III, IV and V - Appendices.

Volume I, as the title suggests, is an overall summary of the Interim Report and summarizes the contents of Volumes II through V.

Volume II is the Technical Report. It has five main sections; the following paragraphs briefly describe how each section is organized.

Section 1

This section documents the results of the Task 2 effort, the state-of-the-art survey. After a brief introduction (Subsection 1.1), Subsection 1.2 provides the findings of the state-of-the-art survey. These are arranged by data source categories:

- Equipment manufacturers
- Trade publications and annual statistics
- Independent organizations and groups
- Past and on-going research programs
- Personal interviews.

Subsection 1.3 identifies the practices and procedures used by bus operators (organizations) in the transportation of handicapped people. This section reports on both school and transit bus operations and documents the available statistics on the demography of the handicapped population.

Subsection 1.4 reviews the local, state and federal regulations as they apply to school and transit bus operations. Particular emphasis is placed on the transportation of handicapped people.

Section 1.5 summarizes the conclusions of the state-of-the-art survey.

Section 2

Section 2 documents the results of the Task 3 effort, the analysis of the injury and fatality data.

After a brief introduction (Subsection 2.1), Subsection 2.2 describes the available data sources and the types of data that are available on bus accidents. Our primary interest is in "intracity" buses, but we also used intercity travel data. Subsection 2.3 documents the findings of the data search as statistical information, relationships between injuries and seating locations, and other findings from similar studies conducted elsewhere.

Subsection 2.4 describes the collision modes, accident frequencies, differences between school and transit buses, and injury severities and their causes. Finally, Subsection 2.5 summarizes the major conclusions of the accident data analysis.

Section 3

This section documents the efforts of Task 4, the development of deceleration crash pulses. The efforts included planning and conducting a series of full-scale bus crash tests.

Subsection 3.1 is a brief introduction to the objectives of the task effort, and Subsection 3.2 describes the school and transit bus crash test program. This description details the test procedures (3.2.1), the test parameters (3.2.2), and the results of the bus crash tests (3.2.3). The results are presented in the following categories:

3.2.3.2 Deceleration crash pulses
3.2.3.3 Structural deformation
3.2.3.4 Dummy trajectories
3.2.3.5 Dummy injury levels
3.2.3.6 Additional information.

Actual test reports and additional test results are contained in Appendices D, E, F and G.

Section 4

This section presents conclusions and recommendations based on the results of Task 2 (Section 1), Task 3 (Section 2) and Task 4 (Section 3).

Section 5

Finally, Section 5 is a brief summary of the remaining work in the program and an outline of the work planned.

Volumes III, IV and V of this report contain a series of appendices. Their contents are briefly described below:

Appendix A - manufacturers, publications and studies surveyed (supplements Section 1 of Volume II)

Appendix B - description of the anthropometry of the U.S. child population (supplements Section 1 of Volume II)

Appendix C - accident data contacts and data sources (supplements Section 2 of Volume II)

Appendix D - deceleration crash pulses derived from bus crash tests (supplements Section 3 of Volume II)

Appendices E, F and G - full test reports of the bus crash tests by individual test bus (supplement Section 3 of Volume II).

SECTION 1
STATE OF THE ART SURVEY

1.1 INTRODUCTION

Task 2 of this contract was to conduct a limited state of the art survey. The survey dealt with the equipment and research available on protective systems for handicapped occupants of buses. The objectives of the survey were to

1. Document the devices, equipment and systems currently being used for transportation of handicapped people in school and intracity transit buses
2. Obtain the operational characteristics of typical school and transit bus transportation systems as they presently are used in the transportation of handicapped people
3. Collect information on the characteristics of handicapped persons, including types of handicaps, age, physical size, and special requirements
4. Analyze the results of completed and on-going occupant safety research and development, as it applies to this program.

The survey results presented in this section were used in other tasks of this program to

1. Establish a baseline representing the equipment and practices that are currently in use in the intracity bus transportation of handicapped people
2. Provide input in the selection of bus types, wheelchairs, wheelchair securement systems, dummy sizes, wheelchair stations and wheelchair orientations during the Task 4 baseline bus crash tests (used to develop deceleration pulses for the sled tests)
3. Establish design goals, guidelines and criteria for the development of crash protection systems for handicapped passengers of buses.

The state of the art survey was principally conducted in the first four months of this program. The data collected were later updated and supplemented with additional information, as it became available during the course of the program.

Figure 1-1 is a block diagram which shows the procedure used in collecting and analyzing data presented in this section.

Subsection 1.2 describes the data categories. Subsection 1.3 presents information on the handicapped population and their bus usage. Subsection 1.4 reviews the Federal, State and Local safety standards and/or regulations, as they apply to school and transit bus operation. The conclusions formulated from the data compiled in the state of the art survey are summarized in Subsection 1.5. Appendix A lists the names of the equipment and systems manufacturers contacted and indicates which of these responded to our inquiries. A complete bibliography (listing all study reports, journal articles, etc. reviewed in this survey) is found at the end of the report.

1.2 FINDINGS OF THE STATE OF THE ART SURVEY

The state of the art survey gathered data from equipment manufacturers, trade publications, independent organizations, government sponsored research programs and personal interviews. This section describes the data collected in the survey.

1.2.1 Manufacturers

We contacted manufacturers of equipment used in the transportation of handicapped persons, especially the manufacturers of wheelchairs, buses, wheelchair securement systems, seats, padding, belts and other related safety devices.

1.2.1.1 Wheelchairs

The wheelchair manufacturers contacted (listed in Appendix A) were asked to supply data on their products. Everest and Jennings provided information

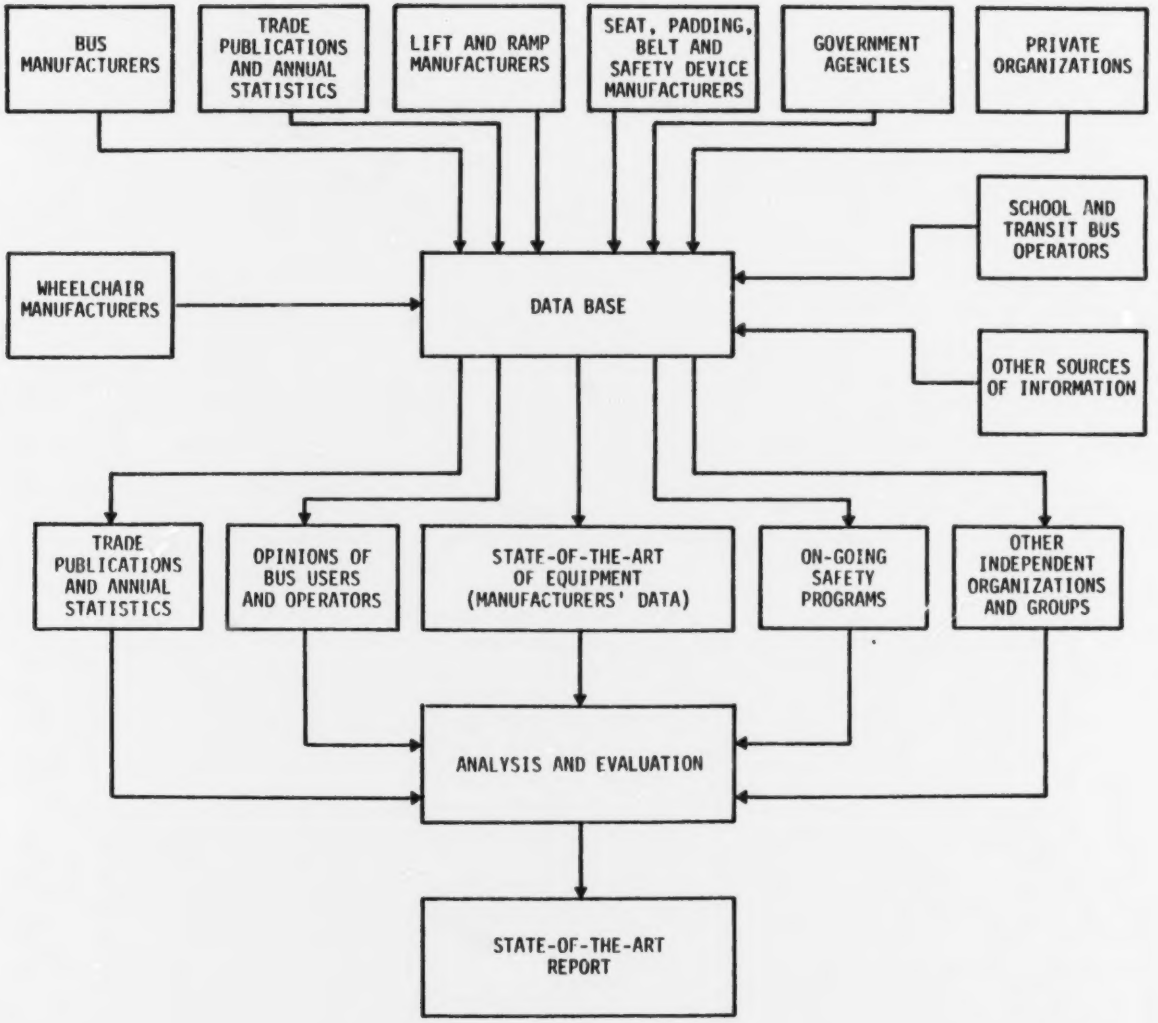


FIGURE 1-1. DATA SOURCES AND PROCESSING FOR THE STATE-OF-THE-ART REPORT

BLANK

PAGE

(Reference 1) on wheelchair safety and handling (which, for instance, specified a maximum grade of 10 percent for self-wheeling) and sent three catalogs (References 2, 3 and 4) describing various wheelchairs – including material on the standard adult wheelchair dimensions and wheelchair safety belts. The latter safety belts, similar to automotive practice, attach to the back frame of the wheelchair. The safety belts are designed to position the user and to provide support during the low acceleration loads imposed by normal operation. (For example, one belt has a Velcro type fastener which most likely would not withstand any high acceleration loads.) Everest and Jennings also maintains a microfilm file (Reference 5) that contains information pertinent to the number of wheelchairs sold, names of purchasers and modifications made.

A careful review of the collected wheelchair data (summarized in Table 1-1) indicated that there is no such thing as a standard wheelchair. Wheelchairs are offered in a variety of models, sizes and configurations. Everest and Jennings, Inc., one of the largest manufacturers, lists over 150 different models. The wheelchair models include:

- Adult chairs in standard, large, narrow and tall variations
- Hemiplegic and amputee versions
- Junior and children sizes
- Special back-support models
- Manual drive and power driven chairs.

Any of these models can be purchased with options, such as

- Fixed, adjustable and specialized types of footrests
- Standard, desk, folding, detachable, and other types of armrests
- Spoked, cast and plastic wheels
- A variety of sizes of wheels
- Conventional, wide, balloon and other types of tires
- Deluxe or basic construction.

The number of variations make it clear why it is difficult to select a "standard wheelchair." The Canyon Research Group (Reference 6) studied a number of types

TABLE 1-1. SUMMARY OF WHEELCHAIR DATA

Manufacturer	Models Offered	Dimensional Data Available	Specific Information
Everest & Jennings	Manual: 24 inch wheels diameter	Yes	All use standard tube frame
	Electric: 20 inch wheel diameter alloy wheel.	No	
Amigo Sales	One basic model electric driven front wheel. Six inch diameter wheel.	Yes	Three wheeled type with steering. Requires good sitting balance and upper body dexterity.
Stainless Metal Production	Manual: 24 inch wheels	Yes	Same construction as Everest & Jennings.
Genderon	Manual: 24 inch wheels; some have small wheels in rear	Yes	Have same construction as Everest & Jennings
	Electric: same size as manual	Yes	
National Wheelchair	Electric: reclining & non-reclining approximately 10-12 inch wheels	No	Square tube construction with wide pneumatic wheels, approximately 10-12 inch diameter with special brakes.

TABLE 1-1. (CONT'D)

Manufacturer	Models Offered	Dimensional Data Available	Specific Information
Colson	Manual: 24 inch wheels	Yes	Same construction as Everest & Jennings
	Electric: 24 inch wheels		
American Stair-Glide	Electric: 8 inch wheels	Yes	Four 8 inch wheels with standard tubular frame.
	Stand-up type, electric 24 inch wheels	Yes	Uses standard Everest & Jennings type wheelchair, seat lifts person into standing position
Theradyne	Manual: 24 inch wheels	Yes	Uses same design as Everest & Jennings
	Electric: 8 inch wheels	No	Uses steel frame with four 8 inch wheels
UC Berkeley	Electric: 12-1/2 inch wheels	Yes	Reclines and will climb 8 inch curbs.
Steven Motorchair	Electric: three wheeled	Yes	16 inch pnuematic wheels in front; 10 inch steering wheel.
Falcon	Electric: 24 inch wheels	Yes	Uses Everest & Jennings wheelchair frame. Modified for reclining.

of wheelchairs. They classified the overall dimensions of wheelchairs in percentiles (Table 1-2). Figure 1-2 shows the dimensions measured for Table 1-2. In the present program Everest and Jennings' Traveler Model (Reference 2) T8A (250/260)-(760/764) was selected as the test wheelchair. The dimensional data for that model are shown in Figure 1-3; the Canyon Research report would typify this wheelchair as an 85th percentile wheelchair.

Variation in size can cause transportation and protection problems. Extra wide wheelchairs and wheelchairs that have extended legrests may not be maneuverable into and through all buses. On the other hand, child-sized wheelchairs might be easily maneuverable, but might not fit into all standard size wheelchair tie-downs.

Most wheelchairs have basically similar construction – except for indoor wheelchairs, which have large front wheels, and some electric wheelchairs, such as the Lakematic (Reference 7), which have four small (8 inch) wheels. According to Everest and Jennings, who produce most of the wheelchairs used in the U.S., five to seven percent of the wheelchairs sold are electric, and the most popular wheelchairs are standard adult size with detachable arms.

Wheelchairs are quite maneuverable, provided there is adequate space. An aisle width of 36 to 38 inches is recommended (Reference 8) for straight travel, although wheelchairs can move through aisles only a few inches wider than the wheelchair itself (about 30 inches).

Wheelchair maneuverability is very important and it is recognized that the crash protection systems developed in this program must not make wheelchair maneuvering more difficult than it is already. Wheelchair maneuverability was investigated by the Canyon Research Group (Reference 6). Their investigations included maneuverability envelopes of the 90th and 100th percentile wheelchairs for 90, 180 and 360 degree turns. Figures 1-4 through 1-7 show the maneuverability envelopes of 90th percentile wheelchairs for four conditions: 90 and 180 degree center pivot turning and 180 and 360 degree reduced wheel pivot turning.

In Subsection 1.4.2 we discuss the UMTA developed guidelines for wheelchair maneuverability envelopes (Reference 75). Two other reports (References 8 and 93) also address maneuverability requirements.

TABLE 1-2. WHEELCHAIR ANTHROPOMETRICS (IN INCHES)

Percentile*	A Overall Length[1]	B Overall Width	C Overall Height	Weight[2]	D Seat Height[3]	E Armrest Height[3]
100	47.00	31.875	53.125	171	23.50	33.25
95	43.25	26.25	38.75	57	20.50	30.25
90	42.50	26.25	38.75	51	20.125	30.25
85	42.00	26.25	38.75	50	20.125	30.25
75	42.00	25.875	38.75	49	20.125	30.25
70	42.00	24.625	38.75	49	20.125	30.25
65	42.00	24.50	38.75	48	20.125	30.25
60	42.00	24.50	38.75	45	20.125	30.25
55	42.00	24.50	38.75	45	20.125	30.25
50	42.00	24.50	38.75	45	20.125	30.125

*Percentile categorization is based on wheelchair weight, dimensions and sales volume; hence, weight and dimension figures, at times, are unchanged at different percentile loads.

Notes:

1. Includes footrigging.
2. Includes footrigging and, if power, two 6V batteries (in pounds).
3. Measured from floor.

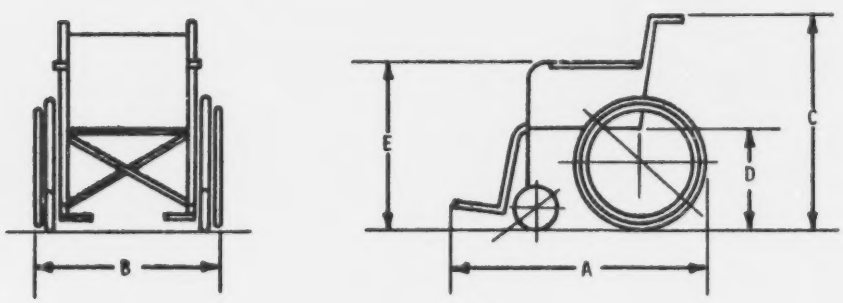


FIGURE 1-2. DIMENSIONS USED IN TABLE 1-2

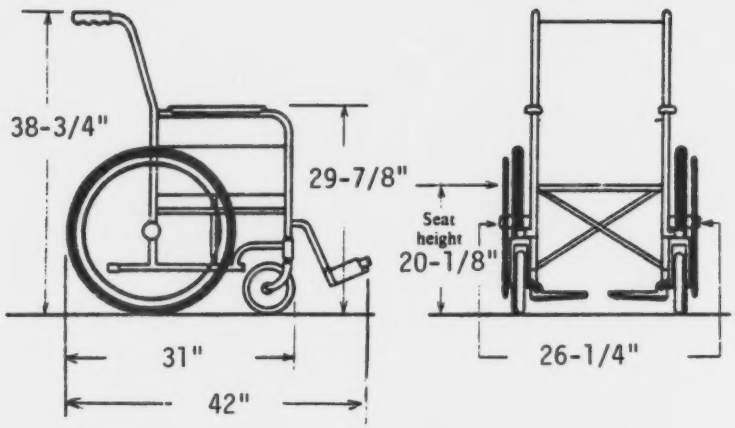


FIGURE 1-3. DIMENSIONAL DATA OF EVEREST AND JENNINGS TRAVELER MODEL T8A (250/260)-(760-764)

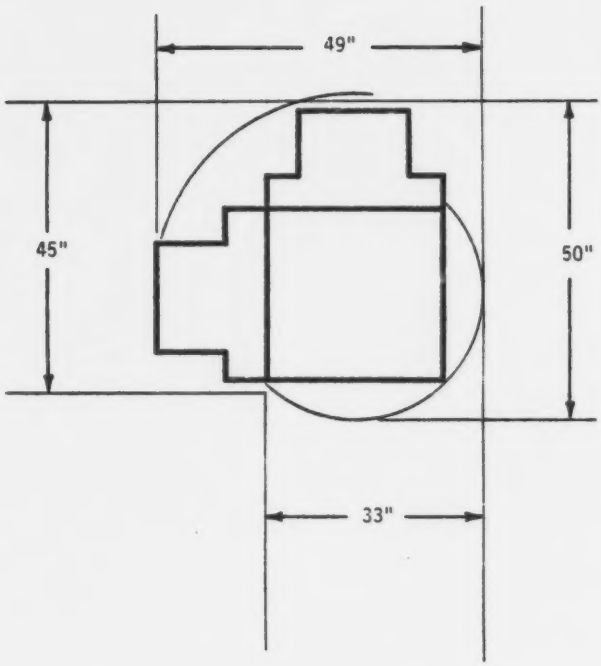


FIGURE 1-4. 90TH PERCENTILE 90 DEGREE CENTER PIVOT

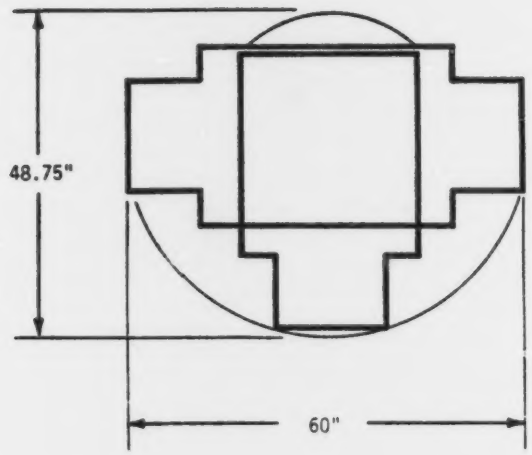


FIGURE 1-5. 90TH PERCENTILE 180 DEGREE CENTER PIVOT

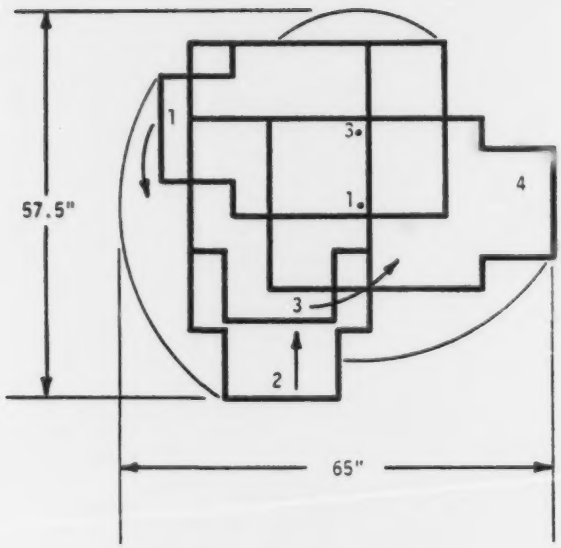


FIGURE 1-6. 90TH PERCENTILE 180 DEGREE REDUCED WHEEL PIVOT

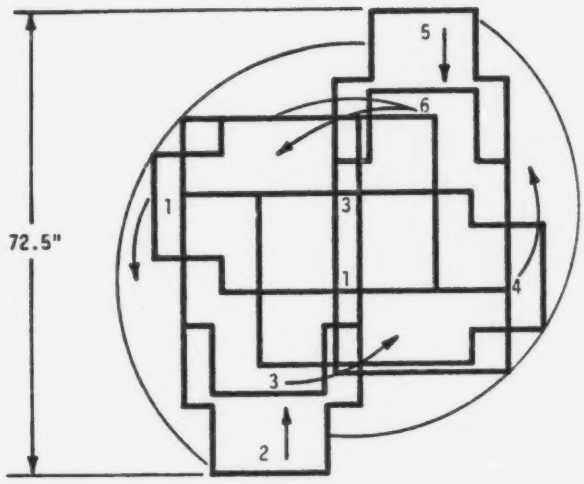


FIGURE 1-7. 90TH PERCENTILE 360 DEGREE REDUCED WHEEL PIVOT

A 10 percent grade is about the steepest grade that can be negotiated without assistance in a nonpower wheelchair (References 9 and 10). Of course, the actual grade negotiable by an individual will vary, depending upon the individual's strength and weight. Since most commercial ramps for wheelchair entry to vans and buses are steeper than 10 percent, assistance is usually required for entering and exiting. The use of a fully automatic lift by a wheelchair seated person requires wheeling onto a platform, either pushing a button or allowing the driver to do so, and wheeling onto the floor of the bus after the lift is raised.

The Veterans Administration (Reference 10) has proposed functional standards for self-propelled, folding and multipurpose wheelchairs. The manual wheelchair described in the standard has to be foldable as a complete unit. It should be comprised of a backrest, seat, armrests, foot plates, propulsion system (manual or electric powered) with drive mechanism, brakes, wheel locks and folding mechanism. Its seat shall accommodate a 95th percentile adult male, and its seat

should be available in a range from 14 to 20 inches wide, and be at least 16 inches long. The maximum floor-to-seat height should be 20 inches. The top of the backrest should be at least 12 inches above the seat, and legrests should be adjustable between 14 to 18 inches (footplate to seat edge). The gross weight of the manual wheelchair shall not exceed 48 pounds. Brake and lock specifications mandate that the brakes, when set, should hold a 200 pound load on a 16 percent slope, when facing uphill, and on a 9 percent slope, when facing downhill, without moving. The brakes should be hand-operable on both sides of the chair, and the brake handles should be at least as high as the seat. The chair must allow its occupant to reach the floor, yet to sit at an average working height. It should be sufficiently maneuverable that the user can propel it through a 28 inch wide door and turn it 180 degrees in a 48 inch corridor. With a 200 pound load, the force required to start on a level surface should not exceed 5 pounds. The wheelchair structure should be capable of withstanding 125 ft-lb of load applied 3600 times without deformation, the load condition and application specified by the standard.

1.2.1.2 School and Transit Buses

We requested information from all of the major U.S. bus manufacturers. Most sent brochures describing their specific products, and some forwarded detailed information on buses specially equipped for the handicapped. These included:

Wayne (Reference 11)	-	Special Care Buses
Blue Bird (Reference 12)	-	Handy Bus
Thomas (Reference 13)	-	Lift Bus
Carpenter (Reference 14)	-	Cadet CV (with lift).

Some companies, such as Superior, Gillig, Carpenter, and Crown, do not make buses with special lifts, but will install the necessary equipment in any of their conventional buses. Coach Equipment (Reference 16) makes special-purpose small buses with provisions for handicapped passengers. Table 1-3 summarizes the data collected on buses that are offered for the transportation of the handicapped.

TABLE 1-3. CHARACTERISTICS OF SAMPLE OF SCHOOL AND COMMERCIAL BUS PROVISIONS FOR HANDICAPPED PASSENGERS*

	Bluebird	Gillig	Thomas	Carpenter	Wayne	Crown	Coach & Equipment Fortibus
Conventional doorway width	--	--	--	--	24-35 inch	--	27, 35 inch
Step heights	--	--	--	--	12-14 inch	--	10 inch
First step depth	--	--	--	--	--	--	9, 10-3/4 in.
Head room	--	75-1/2 inch	--	--	63-77 inch	--	74, 76 inch
Seating, with wheelchairs	Wheelchairs side facing	--	Wheelchairs side facing	Wheelchairs side facing	Wheelchairs side & rear facing	Wheelchairs side facing	Side facing seats drop for wheelchairs
Unitized construction	No	Yes	No	No	No	Yes	No
Lift power source	Electro-hydraulic	Varies	Hydraulic	Electro-hydraulic	Electro-hydraulic	--	Electro-hydraulic
Platform size	--	Lift installed as specified	Wide & narrow lift doors available, dimensions not given	--	29 x 41 in.	--	34-1/2 x 44 inch
Lift door width	35 inch	--	--	--	--	--	43-3/4 inch
Lift door location	Right side between aisles or behind right rear axle	--	Right side between aisles or behind rear axle	Right side between aisles	Just behind door on small buses; anywhere on right side in large buses	Right side between aisles	Just behind standard entrance

*Data presented in this table are based on available information in brochures and data sheets supplied by the manufacturers. No attempt was made to obtain the missing categories of information. Information included was received by March 1978.

TABLE 1-3 (cont'd)

	Bluebird	Gillig	Thomas	Carpenter	Wayne	Crown	Coach & Equipment Fortibus
Capacity, no lift	30-90 pupils	78-90 pupils	16-84 pupils	22-84 pupils	20-66 pupils	79-97 pupils	--
With lifts, no. wheelchairs/ no. seats	Variable	--	1-19/2-44	Variable	Variable	--	--
Aisle width: standard/with wheelchair	12/30 inch	--	12/30 inch	12-1/2 inch	12-16/ variable	12-1/2 inch	--
Wheelchair tiedowns/ restraints	Manual lever, 2 wheel lock (walls)	--	Outside walls, pin-type wheel locks	Manual lever locks mounted on walls	Manual lever locks mounted wall, panel	--	Belt-type from floor
Window exits	Push-out	--	Push-out	--	--	--	--
For non-wheelchaired handicapped	--	--	Side facing seats with belts and/or harness	--	--	--	--
Type of buses made	Medium and large school	Large school	Busette, medium and large school	Medium and large school	School or commercial busette, medium and large school	Large school or transit	Medium, school or

In this program we have classified buses into five categories:

- Small school (or van)
- Medium size school
- Conventional full size school
- Unitized construction school
- Transit.

The general characteristics of these categories of buses are listed in Table 1-4. The first three have separate chassis and body construction, and the last two are of unitized construction (in which the body is integrated into the chassis members to form a single structure).

The transit buses are listed under a single category because they are basically similar in structure. Most are large (35 to 40 foot long) buses, and most (whether large or small) are of unitized construction.

TABLE 1-4. OVERALL CHARACTERISTICS OF FIVE BUS TYPES

Bus Type	Weight (pound range)	Overall Length (foot range)	Seating Capacity (range)	Wheelchair Entry
Van	6,000-8,000	10-14	8-16	ramp/lift
Medium size	8,000-12,000	16-24	16-24	ramp/lift
Conventional full size	12,000-17,000	32-36	60-72	lift
Large unitized	28,000-32,000	32-36	66-97	lift
Large transit	22,000-34,000	35-40	35-40	lift

School Bus Interiors

Seating and interior configurations vary according to bus size and purpose, but some generalizations can be made. In medium and large-sized school buses, there usually are two 3-passenger forward facing seats (39 inches wide) in each row, separated by a 12 inch aisle. A modesty panel is installed in front of the front

seat. Recently constructed buses conform to Federal Motor Vehicle Safety Standard (FMVSS) 222 (Reference 17), a regulation on school bus seating and interiors which became effective 1 April 1977. This standard is discussed in Subsection 1.4.1.

Buses equipped to carry pupils in wheelchairs have a lift or a ramp installed either on the rear or on the right side of the bus. Equipment and arrangements vary greatly, though the aisle width, generally of about 30 inches, is wider than that in a non-wheelchair-carrying bus. California regulations (Reference 18) require only 25 inch aisles to the rear emergency doors for possible emergency evacuation for school buses used in transportation of handicapped students. This can only be achieved by installing narrower seats. In addition, some seats for able-bodied children must be removed to create wheelchair stations. Generally, in conventional full size buses the seating capacity is reduced by about 20, providing for the first wheelchair; these include the seats removed to place a lift, to create a wheelchair station, and to widen the aisle.

Table 1-5 shows how seating is displaced when wheelchairs are accommodated. (The data are from the manufacturers' brochures [References 11 and 13].) As can be seen, each additional wheelchair displaces two or more normal seating positions, the actual number depending on the size of the bus, the position of the wheelwells, the orientations of the wheelchairs (forward or side facing), and the closeness with which the wheelchairs are placed.

The crash protection used in school buses for non-handicapped pupils consists mainly of FMVSS 222 designated seats, seat back padding and seat spacing, seat belts, and wheelchair securements. Wheelchair securement systems are discussed in greater detail in Subsection 1.2.1.3.

School buses can be classified by their seating capacities. The annual statistics of buses purchased from 1967 to 1976 (Reference 19) indicate that 90 percent of the buses are large buses which have seating capacities in excess of 43 pupils. A check with local school bus operators (Reference 20) indicated that small and medium buses are generally used for 'special education' transportation, primarily the transportation of the ambulatory and wheelchair seated handicapped children.

TABLE 1-5. SCHOOL BUS SEATING AND WHEELCHAIR ARRANGEMENT OPTIONS

Bus Make and Model	Wheelchair Spaces Added*	Reduction in Seating Capacity	Space Ratio: Seats/Wheelchairs
Wayne Busette	1	4	4.0
Standard Model	1	1	1.0
	2	3	1.5
	2	6	3.0
Thomas Bus with Double-Door Lift			
2200	9	16	1.8
2210	9	16	1.8
2450	11	20	1.8
2530	11	20	1.8
2610	12	24	2.0
2780	14	24	2.0
2920	16	32	2.0
3000	16	32	2.0
3170	17	36	2.1
3250	17	36	2.1
Thomas Bus with Single-Door Lift			
1720	5	8	2.6
1800	5	10	2.0
1970	7	8	1.1
2050	7	10	1.4
2200	10	18	1.8
2210	10	18	1.8
2450	12	18	1.5
2530	12	22	1.8
2610	13	26	2.0
2780	15	28	1.9
2920	17	32	1.9
3000	17	34	2.0
3170	18	38	2.1
3250	18	38	2.1
			Mean = 2.0

*Includes only wheelchairs added after the lift and first wheelchair installed.

Figures 1-8 and 1-9 show typical school bus interiors of small and large school buses, respectively.

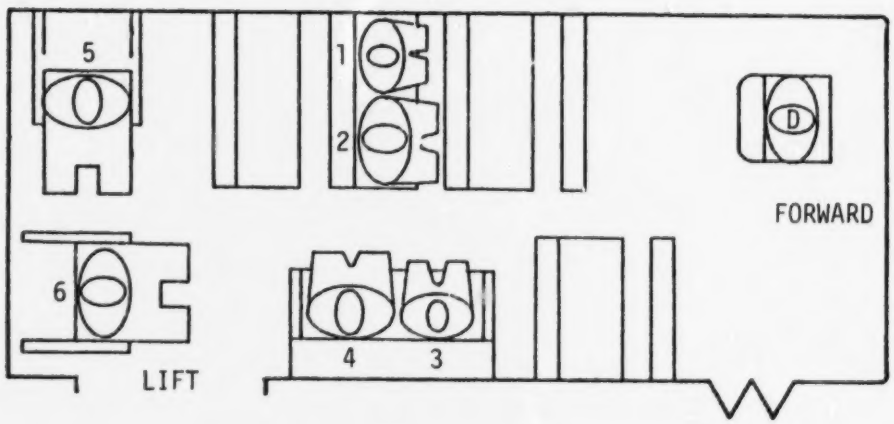


FIGURE 1-8. TYPICAL ARRANGEMENT OF A SMALL SCHOOL BUS USED FOR TRANSPORTATION OF HANDICAPPED PUPILS

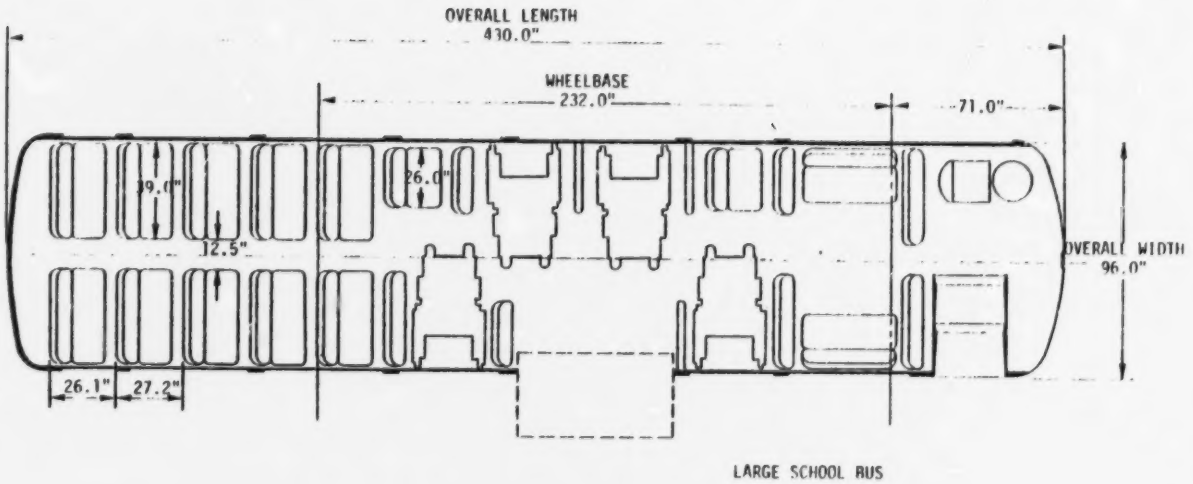


FIGURE 1-9. TYPICAL ARRANGEMENT OF A LARGE SCHOOL BUS USED FOR TRANSPORTATION OF HANDICAPPED PUPILS

Transit Bus Interiors

Transit bus seats are more widely spaced than school bus seats, partially because of the allowances made for standing passengers. At present, there are no federal safety standards for the transit bus seats and modesty panels. The aisles in a transit bus are wider than those in a school bus. Transit buses generally have a forward entry and a rear exit, and include a number of vertical stanchions and grab rails. The front portion of a transit bus has two side facing or longitudinal seats that are usually designated for elderly and ambulatory handicapped people. Some buses have two additional side facing seats just aft of the rear exit. A typical interior arrangement of a large transit bus (one which has two wheelchair stations) is shown in Figure 1-10. The wheelchair station for the typical transit bus generally has a folding seat, so that the non-wheelchair users have seating in the area when the wheelchair station is not in use. When a wheelchair seated passenger is using the station, at least four seating positions are reduced. However, when the wheelchair station is not being used, the folding seat provides two or three seating positions and the standee capacity also may be increased. Large (35 to 40 foot) buses are the most prevalent buses on fixed route systems (Reference 21).

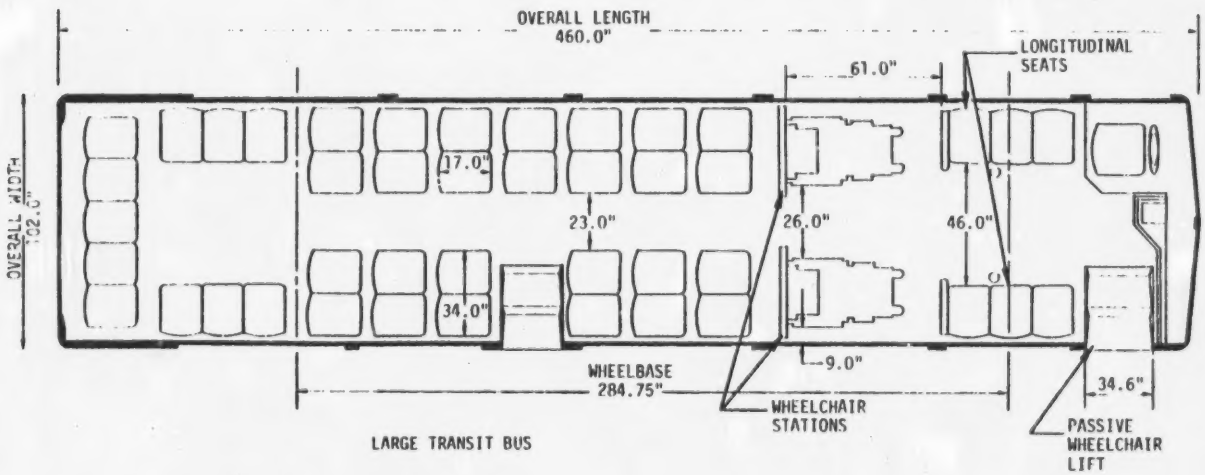


FIGURE 1-10. TYPICAL ARRANGEMENT OF A LARGE TRANSIT BUS USED FOR TRANSPORTATION OF HANDICAPPED PASSENGERS

1.2.1.3 Lifts and Ramps

Table 1-6 summarizes data obtained from lift and ramp manufacturers. The devices are many and diverse in both type and design, varying from simple ramps to hydraulically operated bus steps which turn into lift platforms.

Present wheelchair boarding equipment fits basically into three general classes. In the first (usually used only on vans) are simple ramps (References 25 and 26) that are folded in half and stowed vertically inside the door (Figures 1-11, 1-12 and 1-13). These ramps are the least expensive loading devices. Consequently, they require the most manual labor – they must be positioned by hand and the wheelchair must be pushed up the ramp by an attendant. The ramps investigated in this survey had grades steeper than the 10 percent limit considered to be self-wheelable.

TABLE 1-6. LIFT AND RAMP DATA*

Developer/Manufacturer	Santa Clara County Transit District
Name of Lift/Ramp	Transit Elevator 2
Placement on bus	Side
Operating principle	Rotates 90 degrees out, lowers to ground
Power source	Electrohydraulic or air
How stowed?	Inside door, not compacted
Price	---
Where operated?	---
Retrofit?	Yes
Special features	Wheelchair station inside bus facing forward in line with the seats. May remain there to ride, or move elsewhere.
Type of vehicle for which designed	Transit bus
Developer/Manufacturer	Collins
Name of Lift/Ramp	Collins Saf-T-Lift
Placement on bus	---
Operating principle	Platform lowers, semi- or fully automatic
Power source	Electrohydraulic (manual override)
How stowed?	Platform stored vertical, rotates to horizontal
Price	---
Where operated?	Exterior (optional) hand-held (optional) console
Retrofit?	Yes
Special features	No header bar; fully or semi-automatic (for use with or without attendant); safety flap
Type of vehicle for which designed	Van, school bus, ambulance
Developer/Manufacturer	Collins
Name of Lift/Ramp	Saf-T-Ramp
Placement on bus	Any door
Operating principle	Ramp on edges, steps between
Power source	Attendant
How stowed?	Vertical, inside door
Price	---
Where operated?	Not applicable
Retrofit?	Yes
Special features	None
Type of vehicle for which designed	Van

*Data presented in this table are based on available information in brochures and data sheets supplied by the manufacturers. No attempt was made to obtain the missing categories of information. Information included was received by March 1978.

TABLE 1-6 (Cont'd)

Developer/Manufacturer	Collins
Name of Lift/Ramp	Econo-Ramp
Placement on bus	Any door
Operating principle	Plain flat surface
Power source	Attendant
How stowed?	Vertical, inside door
Price	---
Where operated?	Not applicable
Retrofit?	Yes
Special features	None
Type of vehicle for which designed	Van

Developer/Manufacturer	Transportation Design and Technology
Name of Lift/Ramp	Electrohydraulic Handicap Lift
Placement on bus	Standard entry door
Operating principle	Steps flatten to become 36 inches long, 35 inches wide; platform lowers
Power source	Electrohydraulic
How stowed?	In form of normal entrance steps
Price	$4,500
Where operated?	From driver seat or from wheelchair
Retrofit?	Most transit buses and motor homes
Special features	Safety flap. Entire step unit may be lowered (intact) to assist elderly.
Type of vehicle for which designed	Transit bus, motor home

Developer/Manufacturer	Handi-Ramp
Name of Lift/Ramp	29 models available
Placement on bus	Any door
Operating principle	Ramp with or without steps
Power source	Attendant
How stowed?	Vertical, folded in half inside door
Price	$358.25 to $607.46
Where operated?	Not applicable
Retrofit?	All vans
Special features	None
Type of vehicle for which designed	Van, hospital vehicle

TABLE 1-6 (Cont'd)

Developer/Manufacturer	Braun
Name of Lift/Ramp	Braun Lifter
Placement on bus	Side or rear door
Operating principle	Fully or semi-automatic, folds down and lowers
Power source	Electrohydraulic
How stowed?	Vertical, inside door
Price	$995 to $2,170
Where operated?	Variable to suit
Retrofit?	All vans, custom fitted
Special features	Safety flap
Type of vehicle for which designed	Van conversion

Developer/Manufacturer	Para Industries
Name of Lift/Ramp	Transilift
Placement on bus	Side for transit; side or rear for school bus
Operating principle	Steps deploy, become platform
Power source	Electrohydraulic
How stowed?	In form of steps
Price	---
Where operated?	Driver seat
Retrofit?	---
Special features	Grab rails in both platform and step mode, audible and visible warning when lift in use
Type of vehicle for which designed	Transit bus

Developer/Manufacturer	Para Industries
Name of Lift/Ramp	Paralift
Placement on bus	Van side doors
Operating principle	Platform folds down and lowers
Power source	---
How stowed?	Vertical, inside door
Price	$1,943 to 2,756
Where operated?	Beside platform (inside) and outside
Retrofit?	All vans
Special features	Outside switch automatically opens doors and lowers platform
Type of vehicle for which designed	Van and school bus

TABLE 1-6 (Cont'd)

Developer/Manufacturer	Fred Scott and Sons
Name of Lift/Ramp	Hydraulic Translift
Placement on bus	Side or rear entry
Operating principle	Platform folds down, lowers, semi- or fully automatic
Power source	Electrohydraulic
How stowed?	Vertical, inside door (8 inches)
Price	$1,069 to $2,450
Where operated?	---
Retrofit?	All vans
Special features	Only 8 inches inside van in stowed position; doors open and close electrically
Type of vehicle for which designed	Van or bus
Developer/Manufacturer	City Machine and Tool Division, Sheller-Globe
Name of Lift/Ramp	Courtesy Lift CMT2
Placement on bus	Normal step entry
Operating principle	Steps turn into platform, lower
Power source	Electric, manual override
How stowed?	In form of steps
Price	$6,375 not installed
Where operated?	Main controls by driver; up/down control also on remote control unit
Retrofit?	Bus with 37 inch door
Special features	Safety flap; automatic stop on contact
Type of vehicle for which designed	School bus
Developer/Manufacturer	Environmental Equipment Corporation
Name of Lift/Ramp	---
Placement on bus	Rear, side entry
Operating principle	Fold down and lower
Power source	Electrohydraulic
How stowed?	Vertical, inside door
Price	$2,195
Where operated?	---
Retrofit?	---
Special features	Safety flap
Type of vehicle for which designed	Van, transit bus
Developer/Manufacturer	Target Industries
Name of Lift/Ramp	---
Placement on bus	Side or rear entry
Operating principle	Power up, gravity down, semi- or fully automatic
Power source	Electrohydraulic
How stowed?	---
Price	$1,565; $2,495 installed
Where operated?	Outside and inside
Retrofit?	Yes
Special features	Can be used as an exit even with a dead battery
Type of vehicle for which designed	Van, Mercedes Minibus, large bus

FIGURE 1-11. COLLINS' SAF-T-RAMP

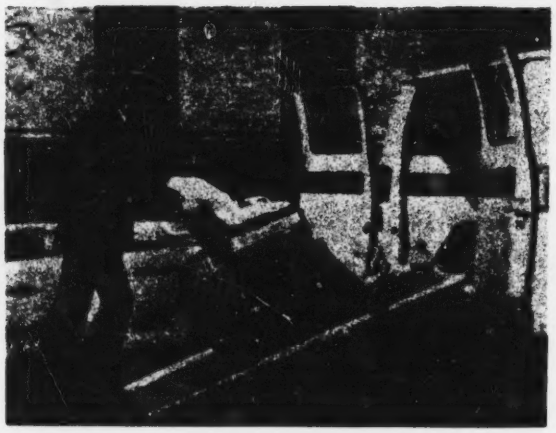


FIGURE 1-12. HANDI-RAMP, IN-USE

FIGURE 1-13. HANDI-RAMP BEING DEPLOYED

The second class of boarding equipment consists of electrohydraulically operated lifts (References 27 and 28), which usually have a platform (stored vertically) that folds out automatically and lowers to the ground (Figures 1-14, 1-15 and 1-16). In one design (Reference 29) the platform is stored flat on the floor and is rotated out in order to lower to the ground (Figure 1-17). These lifts are commonly used for school and special handicapped transportation services (Figure 1-18). The volume occupied varies from lift to lift. The vertically stowed lifts extend 14 inches or more horizontally into the vehicle and 40 to 50 inches lengthwise along the wall. The folded platform is a likely hazard in a crash because passengers could be thrown against protrusions and corners of the metal surfaces.

Stepwell lifts (References 30 and 31; Figures 1-19 and 1-20) comprise the third class of boarding equipment. These are automatic lifts which transform, in a variety of ingenious ways, into platforms. The stepwell lifts are presently being developed; some are being produced now, but few are actually in use. These lifts are the most complex and the most expensive, but they are the most space efficient, since they do not require an additional entrance. Stepwell conversion lifts appear to be well suited for regular fixed route transit buses, because they allow the boarding handicapped passenger to pass the fare box at the forward entrance. The stepwell lifts appear to have fewer impactable protruding parts in the passenger compartment than do the vertically stowed platform lifts, and thus are less likely to be hazardous in a crash, since they are mounted in front of the modesty panel – away from the passenger locations.

The second and third classes of lifts may have any of a number of safety features: safety flaps that fold up to form a barrier (several inches high) to prevent the wheelchair from rolling off the platform, pressure sensitive tape on the edge of the platform which causes the lift to halt upon contact with any obstruction, manual override systems in case of power system failure, grab rails, and audible or visible warning systems which operate when the lift is in use. Most of the electrohydraulic lifts available are fully automatic, and are operated from the driver's seat. No assistance would be required for wheelchair occupants who are capable of wheeling themselves. An additional feature of the

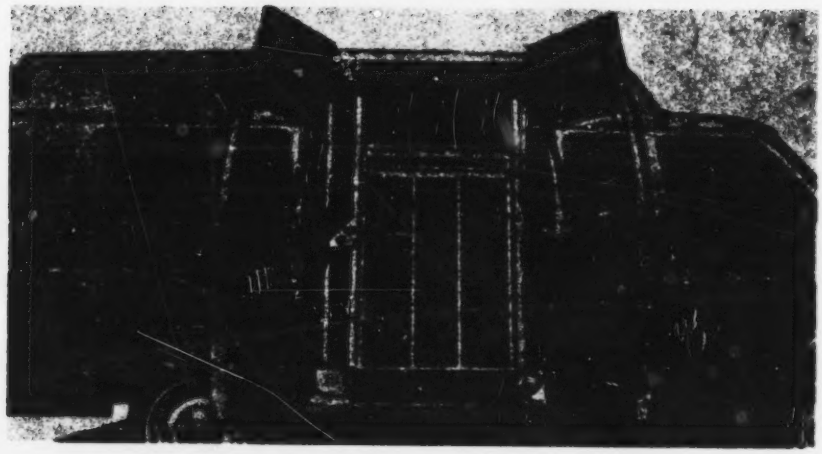


FIGURE 1-14. BRAUN LIFT, STOWED

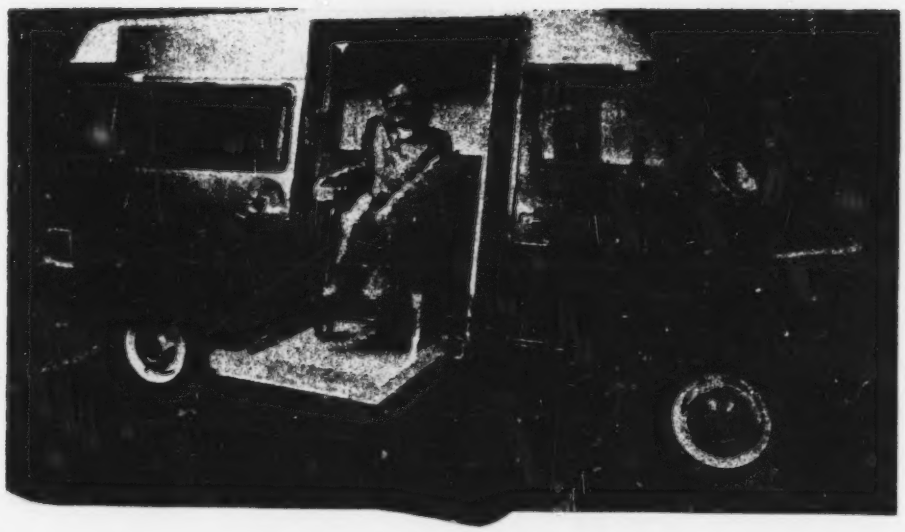


FIGURE 1-15. BRAUN LIFT, IN-USE

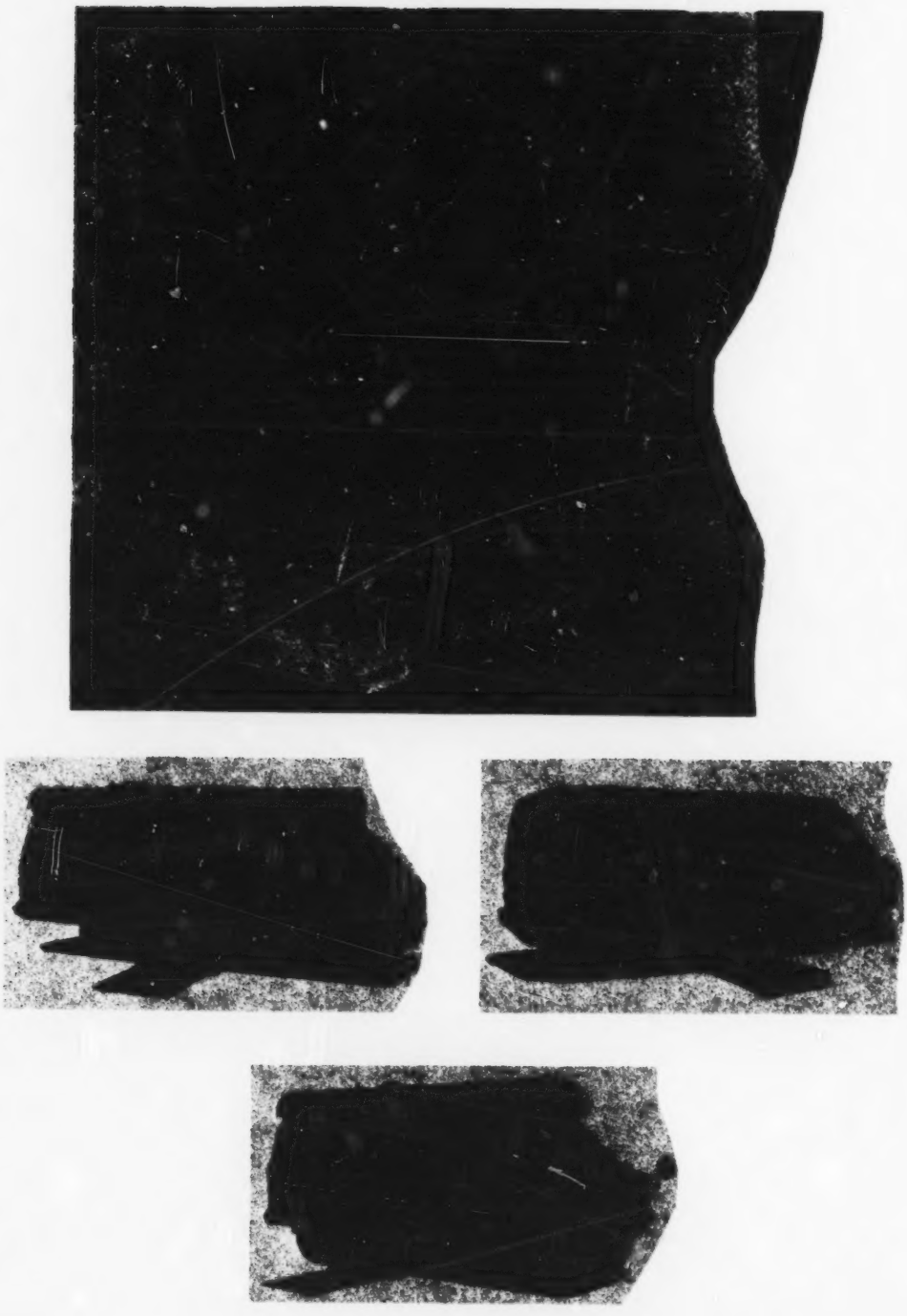
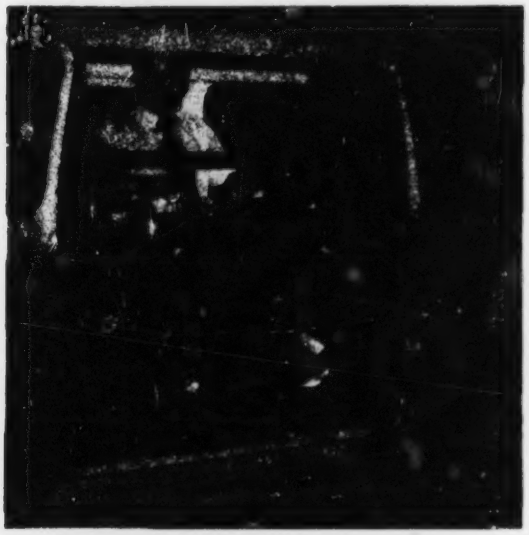


FIGURE 1-16. COLLINS SAF-T-LIFT



Stowed in the Vehicle

Deployed on the Pavement

FIGURE 1-17. MAXON SWING LIFT

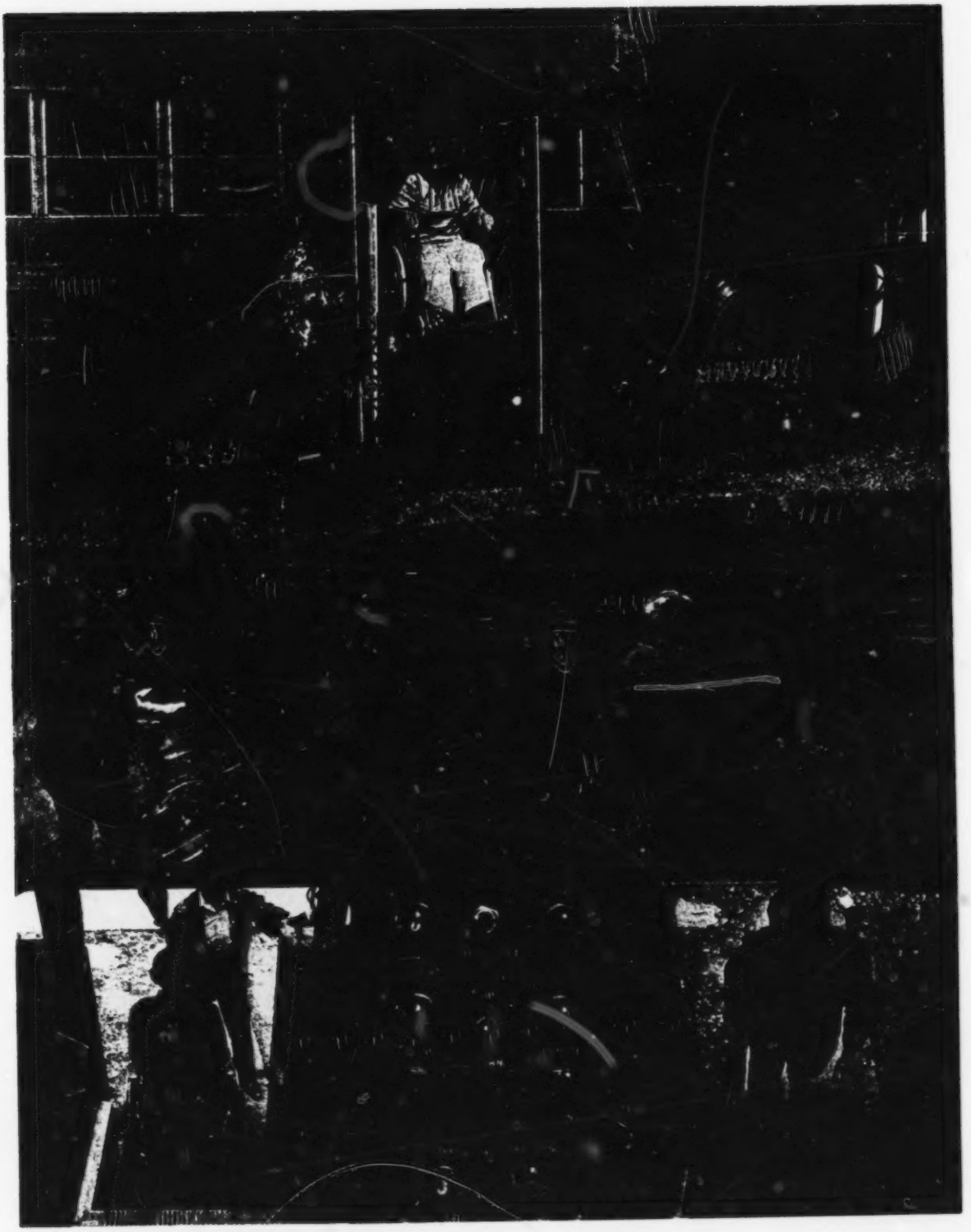


FIGURE 1-18. COURTESY LIFT – CTM2

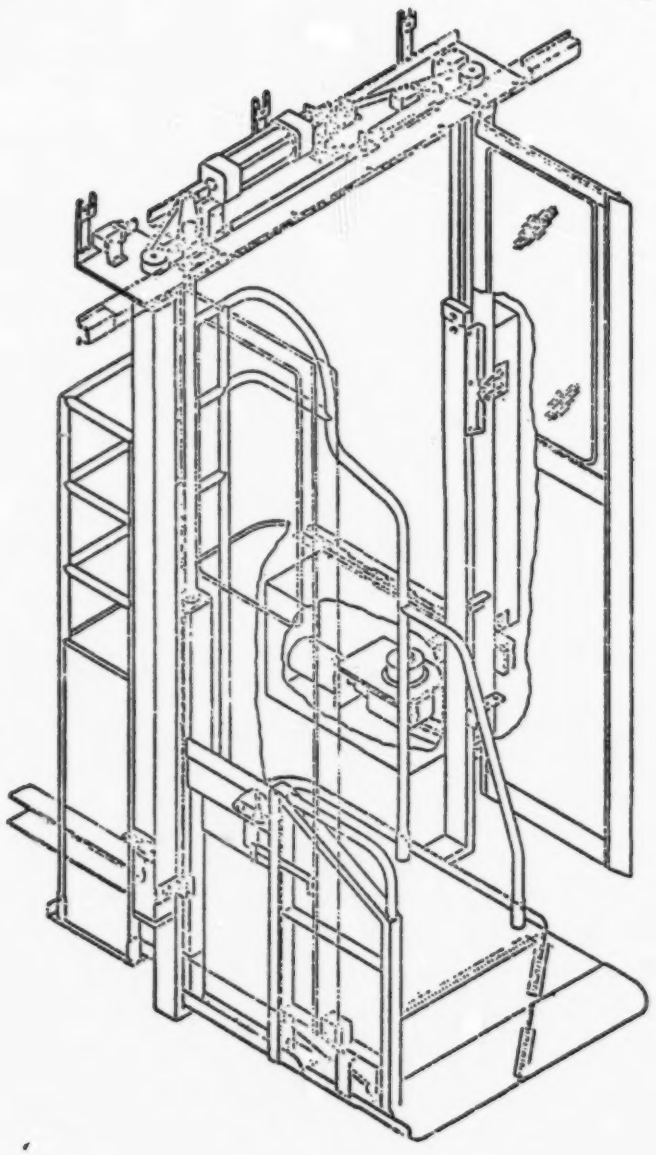
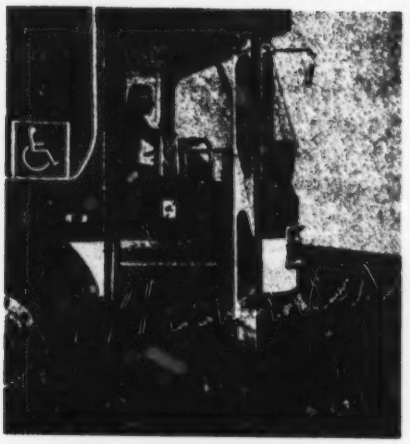
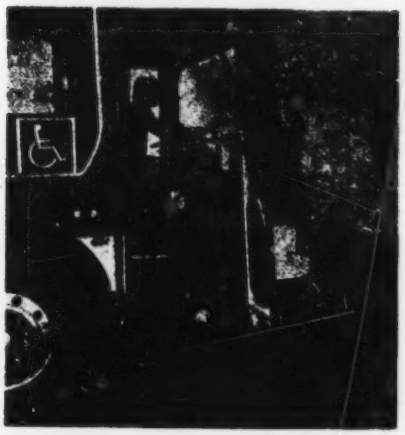


FIGURE 1-19. TRANSIT ELEVATOR – SANTA CLARA COUNTY TRANSIT DISTRICT

STEP CONFIGURATION

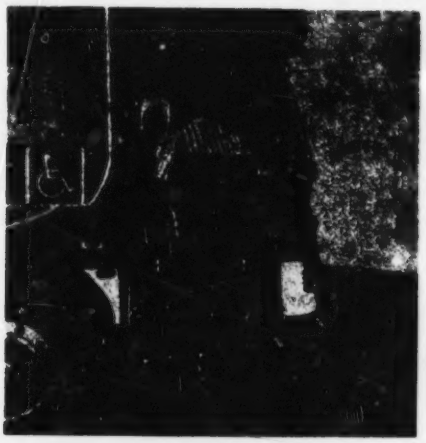


PLATFORM DEPLOYING



PLATFORM DEPLOYED

PLATFORM LOWERED



PLATFORM RAISED

FIGURE 1-20. TRANSIT BUS STEPWELL LIFT

stepwell lift manufactured by Transportation Design and Technology of San Diego, California (Reference 30) is that the entire step unit will lower and raise as a step, to assist the entrance of ambulatory, elderly or handicapped passengers.

The Veterans Administration has set wheelchair lift standards (Reference 10) on the basis that paraplegic persons do not have the capabilities of strength, reach, and grip necessary to operate mechanical equipment. These persons may also have visual, equilibrium, or tactile limitations that affect their ability to control lifts. The standards require a lift load capacity of at least 400 pounds (based on the weight of a 95th percentile adult male (217 pounds), 8 pounds of clothing, and a 150 pound wheelchair – for a total of 375 pounds. It is also suggested that lift handholds have an approximately 1-1/2 inch diameter round cross section. The VA reports (Reference 10) that lift users comment favorably about being able to hold on to something for stability, but state that square tube handrails are less comfortable than round tubes. Lifts should provide a platform 29 inches wide for the wheelchair – this leaves the 25 inch wide (70th percentile) wheelchair 2 inches clearance on either side for maneuvering space. The same width should be allowed between any vertical framework.

The interior height from the ground or platform to any lateral member shall be at least 32 inches. It should not be necessary to turn on the platform to use the lift, because it is difficult for the occupant to see the floor and wheelchair wheels while sitting in the chair. Ideally, the actions required of the user should be minimized, so that a broad range of handicapped persons are able to operate the lift. Manual operation should be possible, in case the primary power source fails. The lift should be able to withstand (but not raise) a load of 2400 pounds – to allow a safety factor of six for the 400 pound design load.

1.2.1.4 Wheelchair Securements

The commercially available wheelchair securement systems (References 32 through 37) can be grouped together as five basic generic types of devices. These devices vary widely in mounting location and in the amount of effort and assistance required for operation. They also differ in the wheelchair

orientations they permit. Some of these devices, such as the wall-mounted rim pins, accommodate only a side facing wheelchair Others, as the cargo belt securement systems, can easily accommodate side facing, forward facing and rear facing wheelchairs.

Except for cargo belts, wall rim pins (Reference 38; Figure 1-21) based on our observations are the commonly used means of securement. These devices hold the large wheelchair wheels at axle height. The wheelchair is backed up to the wall-mounted flanges, and a pin is slipped between the spokes to secure the rim. The means of securing the pin varies from totally manual (pushing the pin through the flanges) to totally automatic (spring loaded, activated by backing the wheelchair in). The manual and automatic devices are released, respectively, by pulling the pin out or pulling a release lever. Unfortunately, the manual type is located out of reach from the wheelchair. The automatic could be managed by most wheelchair users without assistance, but a smaller or weaker person may not be able to release the lever.

A second type of securement is similar to the rim pin, but is mounted on the floor (Reference 38) and holds the bottoms of the wheel rims (Figure 1-22). About the same degree of assistance is required.

The third securement is the T-bar (Reference 39; Figure 1-23), which is mounted to the floor and secures the lower horizontal frame of the wheelchair. This device is completely out of reach for the wheelchair user and requires assistance for operation.

Fender brackets (Reference 40) attached to posts mounted on the floor (Figure 1-24) make up the fourth securement type. To secure the wheelchair, the brackets are first moved to a position just above the wheels, then are pushed down on the wheels. The mechanisms are spring-loaded, and considerable force is necessary to clamp them down on the wheels. A small, lightweight person could not clamp these brackets. The brackets are released by pulling a lever. All of the operating parts are within reach of the wheelchair occupant.

Cargo type belts (Reference 32) of different variety (Figure 1-25) comprise the fifth type of wheelchair securement. In this system either floor or wall mounted

FIGURE 1-21. WALL RIM PIN

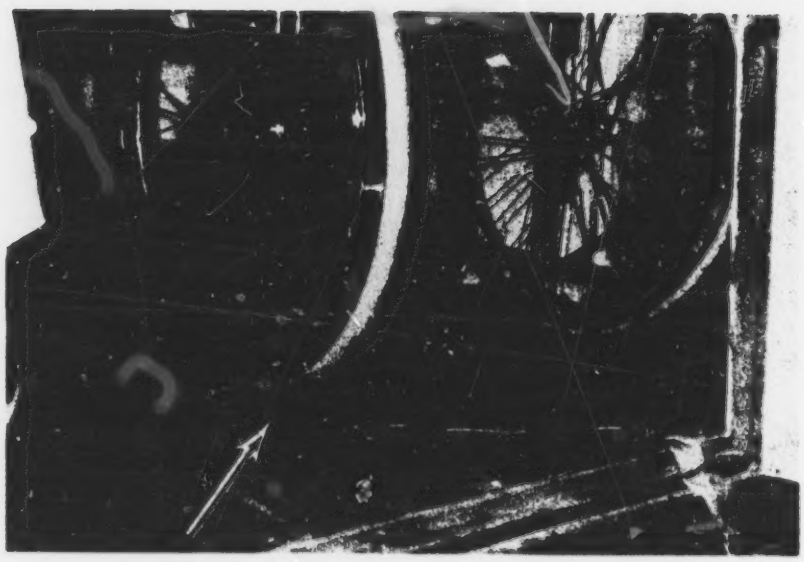


FIGURE 1-22. FLOOR-MOUNTED RIM PIN SECUREMENT

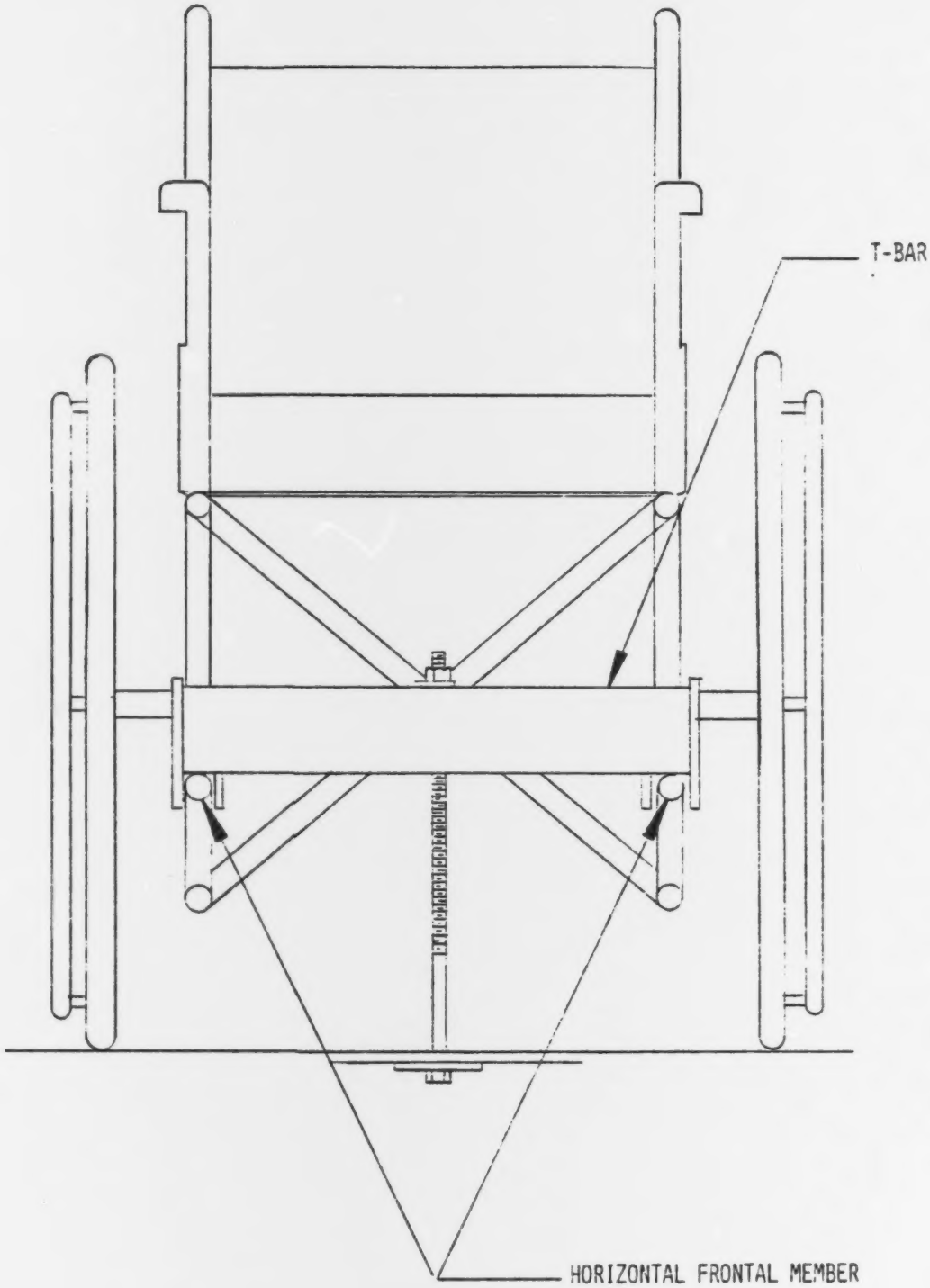


FIGURE 1-23. T-BAR WHEELCHAIR SECUREMENT

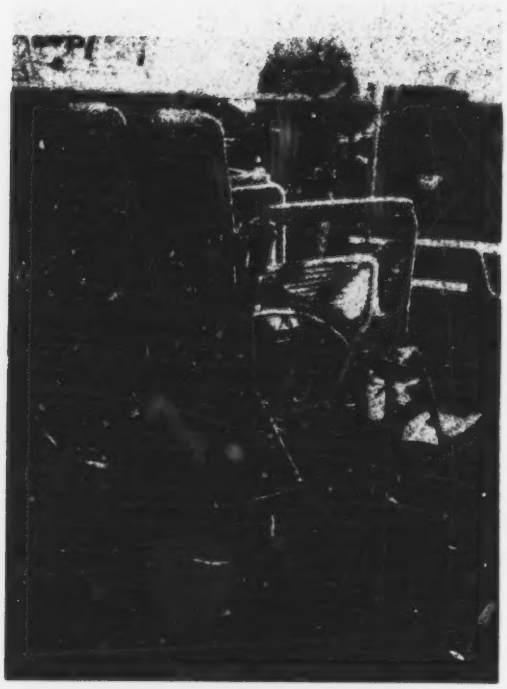


FIGURE 1-25. CARGO BELT SECUREMENT

tracks accept one end of the securement belt via a quick connect/disconnect buckle. The other end is looped around a convenient structural member of the wheelchair and then is connected at another point on the track. Generally the wheelchair is secured at least at three, and more firmly at four, structural points of the wheelchair. This securement system cannot be fastened and unfastened by the passengers in wheelchairs. The assistance is provided by either the driver or somebody traveling with the wheelchair seated passenger. In one variation of this securement system, a longer belt is used to secure both the wheelchair and the passenger. This belt is passed around the seated passenger and anchored on the floor behind the wheelchair. Obviously, such an arrangement is likely to load the occupant with the weight of the wheelchair during an accident. The five securement types are generally adjustable or flexible enough to accommodate the sizes of the standard wheelchair models. Powered wheelchairs and non-standard sized wheelchairs are generally accommodated by cargo belt securement systems. The other four securement types may not be able to secure the powered and the non-standard manual wheelchairs.

Table 1-7 lists some of the commercially available wheelchair securement systems, their mechanisms and mounting locations.

1.2.1.5 Padding, Belts and Other Safety Devices

Table 1-8 lists information received from safety device manufacturers. These devices are special harnesses to be used for wheelchair seated or ambulatory handicapped passengers.

Figures 1-26 through 1-28 show the Collins Saf-T-Straint (Reference 41), the Dubl-Life Saver (Reference 42) and the E-Z-On Harness (Reference 43). Each of these devices seems to rely on the principle of distributing the impact load over a wider area of contact, but their effectiveness has not been tested.

TABLE 1-7. SOME WHEELCHAIR SECUREMENT SYSTEMS

Manufacturer and Securement System	Mechanism	Operation	One or Two Wheels	Mounting Location
Collins Saf-T-Lock	Pin lock-wheels	Semi-automatic Semi-automatic (lever) Automatic (lever)	2	Anywhere on floor
Tye-Chair	Belt-locks frame	Manual (not by wheelchair occupant)	NA	Floor
Handi-Ramp, Inc. Handi-Clamp	Pin wheel locks	Manual	2	Wall or floor
Handi-Ramp, Inc. Belt Clamp	Belt around front of wheelchair arms	Manual	NA	Floor or wall
Handi-Ramp, Inc. Wheel Well	Two wheel shaped wells, 3 to 7 inches deep	Wheel into well	2	In floor
American Seating Co.	Single rim clamp	Wheel into clamp	1	Under folding seat

TABLE 1-8. SOME COMMERCIALLY AVAILABLE RESTRAINT SYSTEMS

Name	Type	Mounting Location
Collins Saf-T-Straint	Automotive type seatbelt with wide padded torso cushion	Wheelchair
Collins Torso-Restraint	Belt with wide padded torso section for elderly or handicapped	Mounts on back of bus seat, removable
Dubl-Life Saver	Belt with wide padded torso section for handicapped	Mounts on back of seat, removable
Rupert Heavy Duty Harnesses	Shoulder, torso and crotch harnesses; nylon webbing, buckles	Floor
E-Z-On Harness	4-point torso harness of webbing	Seat back

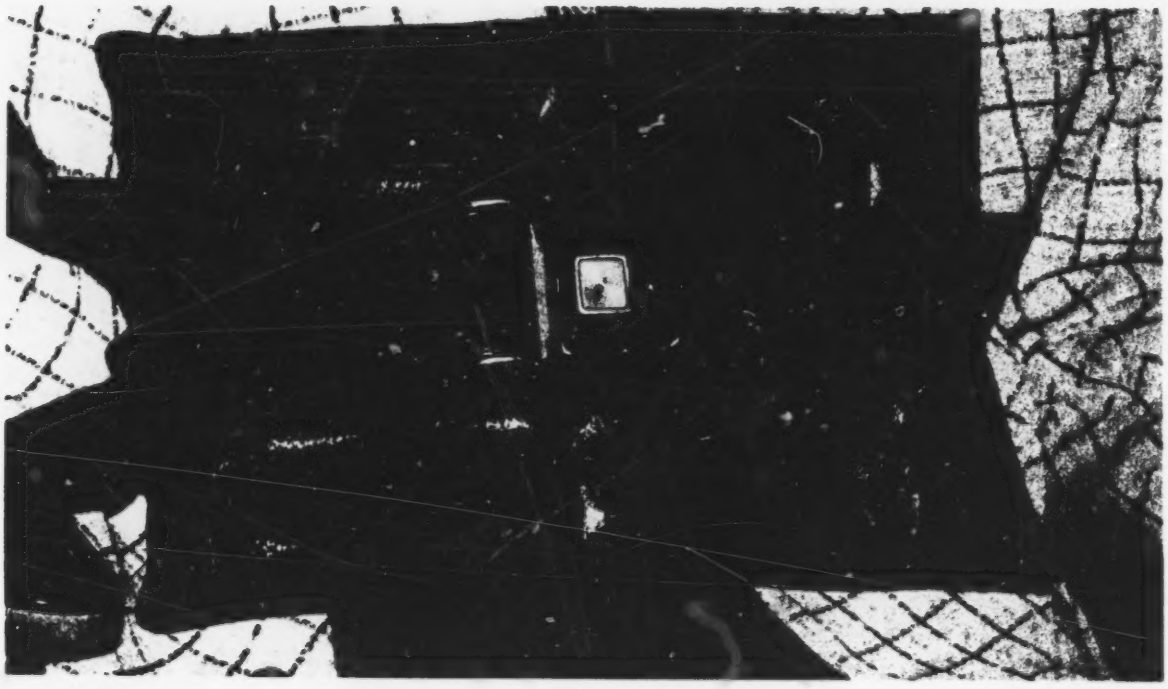


FIGURE 1-26. COLLINS SAF-T-STRAINT

FIGURE 1-27. "DUBL-LIFE-SAVER": A SUPPORT RESTRAINT VEST

FIGURE 1-28. "E-Z-ON": A RESTRAINING HARNESS

Most wheelchair manufacturers offer a seat belt as an option. A typical Everest and Jennings wheelchair lap belt arrangement (Reference 44) is shown in Figure 1-29. The lap belts offered by wheelchair manufacturers are primarily designed to hold the person in the wheelchair during operational loads (braking and cornering); they are not designed or mounted to withstand crash induced loads, or to protect the person in such conditions.

FIGURE 1-29. EVEREST AND JENNINGS WHEELCHAIR BELT

1.2.2 Trade Publications and Annual Statistics

A useful source of information was "School Bus Fleet" (Reference 11), a bimonthly publication about school buses and related equipment. It supplied fairly complete lists of bus manufacturers and distributors, and its advertisements even included safety systems, such as the E-Z-On Harness, the Tye-Chair and the Dubl-Life Saver, all of which are described above. There also were advertisements for the Swing-Away Lift (Reference 24), an hydraulic add-on wheelchair lift which rotates 90 degrees out the door and lowers to ground level, and the Easy-Way (Reference 46) replacement back covers and seat cushions, which are padded protective seat covers that "update buses already in service and enhance pupil safety."

"School Bus Fleet" also included an article (Reference 47) entitled, "Seat Construction Guidelines Require Extensive Lab Tests," describing the American

Seating Company effort to design and extensively test school bus seats to meet the FMVSS 222 requirements. American Seating applied forward and rearward loads to the seat back to test its energy absorbing characteristics in accordance with FMVSS 222. The company also conducted head impact tests. In addition to the FMVSS 222 testing, American Seating Company simulated swing, drop and squirming loads (100,000 squirms using wooden buttocks weighted to 150 pounds). The school bus seats are available in 27 and 39 inch widths for original or retrolift installation.

The "School Bus Fleet" magazine editorials typically reflected the point of view of bus manufacturers. One 1977 editorial (Reference 48) compared the 4700 injuries and 35 deaths involving school bus passengers in 1973 to the annual 410 to 1000 deaths of bicycle riders (based on statistics from 1935 to 1974). The point of the editorial was that the government is imposing regulations on school buses, which actually have a fairly good safety record.

The "School Bus Fleet" annual statistical information issue (Reference 19) contains tabular data on school bus operations. The information that was found useful for this program included:

- List of school bus manufacturers
- Dimensional and chassis information data on buses
- Accident statistics
- Statistics of school transportation.

Tables 1-9 and 1-10 show the sort of information available from "School Bus Fleet" magazine (Reference 19). These tables give the numbers and percentages of school buses sold from 1974 to 1977 for the major bus weight and passenger capacity categories.

1.2.3 Other Independent Organizations and Groups

During the state of the art survey we contacted a number of independent organizations and obtained useful information from several private publications.

TABLE 1-9. "SCHOOL BUSES SOLD" STATISTICS (1974-1977) BY BUS WEIGHTS

Gross Vehicle Weight (GVW) (pounds)	Number of Buses Sold (Year) 1974	1975	1976	First 9 Months of 1977	Approximate Passenger Capacity
4,000 to 16,000	168 0.5%	178 0.5%	0	0	20-35
16,001 to 19,500	2,018 5.5%	908 1.7%	393 1.1%	173 0.7%	35-48
19,501 to 26,000	31,752 87.4%	31,281 92%	31,019 90.5%	25,156 95.1%	44-72
26,001 to 33,000	304 0.8%	176 0.5%	1,322 3.9%	344 1.3%	66-84
Over 33,000	2,102 7.4%	1,458 4.3%	1,547 4.5%	781 2.9%	78-90

TABLE 1-10. "SCHOOL BUSES SOLD" STATISTICS (1967-1971) BY BUS CAPACITY

Number of Passengers	Number of Buses Sold (Year) 1967	1968	1969	1970	1971
12-48	2,200 10%	2,025 9%	2,687 11%	2,843 10.5%	3,031 10.9%
49-60	11,440 52%	11,363 50.5%	11,483 47%	12,239 45.2%	12,112 43.4%
Over 61	8,360 38%	9,112 40.5%	10,261 42%	11,995 44.3%	12,765 45.7%

Some of the members of the California Association of the Physically Handicapped (CAPH) (Reference 49) visited Minicars to discuss the project and to give their opinions of the needs and problems of the handicapped in buses. Two of their major recommendations were:

- Release levers should be provided on both sides for wheelchair tie-downs, because many wheelchair occupants have only one usable arm (or one stronger than the other).
- Mechanisms should be made simpler so that they can be pushed by the palm of the hand, thereby requiring less finger dexterity and strength.

The CAPH provided feedback and response to our design criteria as they were developed.

Minicars also tried to obtain data from several insurance companies providing coverage for transit buses. For legal reasons, insurance companies have the policy not to divulge statistics, so little information was obtained from these sources. Some companies did mention that wheelchair occupants are less likely to ask for accident compensation. They usually settle for medical and equipment expenses. They also mentioned that most bus-related injuries are not actually crashes, but are due to people (mostly the elderly) falling inside the bus. One agent mentioned a case in which an electric wheelchair ran off the platform after accidentally being turned on during loading.

Articles and reports prepared by private organizations provided much useful information. For example, the 1967 issue of "Urban Bus Design Objectives" (Reference 50) specified the qualities and characteristics transit operating companies deem desirable. Some of these are listed in Table 1-11. These specifications do not include provisions that are special for transportation-handicapped people.

We also reviewed the "A.C. Transit Elderly and Handicapped Planning Study" (Reference 51). The study included only people in the Oakland, California, transit district (2,104), and the data are indicative of the U.S. public in general (Tables 1-12 through 1-14).

TABLE 1-11. URBAN BUS DESIGN OBJECTIVES*

Description	Specification
Floor height	Not more than 32 inches at front and rear entrances
Steps:	
Bottom	Not more than 12 inches from ground
Tread depth	Approximately 12 inches
Second step depth	Approximately 10 inches
All risers	Not more than 9-1/2 inches
Aisles	Minimum of 20 inches, but as wide as possible
Fare box	Provision for installation of a fare box at a position convenient for passengers depositing fares
Stepwell lights	Adequate illumination of stepwells and ground area for approximately 4 feet from steps; minimize shadows and glare
Seat spacing	Minimum center-to-center spacing of 28-1/2 inches and knee room a minimum of 9-1/2 inches
Supports	Transverse seats should have 1 inch bar across top for handgrip
Armrests	Transverse seats should not have aisle side armrests; longitudinal seats should have armrests on both ends
Seat backs	Slope of 105 degrees from floor; height of 19 inches from seat cushion
Doors	Folding doors should open fully and lock there in the event a passenger grabs handle; in future bus design, doors should be wider than in present design
Stepwells	Treads should be covered with nonskid material and step edges should be of a distinctive contrasting color
Sensitive edges	Provision for equipping doors with a sensitive edge to audibly or visually signal to driver, or to stop or reopen the door automatically when it hits an obstruction
Floor covering	Floor covering should be nonskid
Stanchions and handrails	These should be located to adequately support passengers without interfering with movement

*Reference 50.

TABLE 1-12. LABOR FORCE STATUS OF TRANSPORTATION HANDICAPPED (T.H.) BY SEVERITY*

	Working					
	Full-time (%)	Part-time (%)	Student (%)	Keep House (%)	Retired or Not Looking (%)	Unemployed Looking for Work (%)
Of all T.H.	12	7	5	9	59	7
Slightly T.H.	24	8	8	9	44	8
Moderately T.H.	7	8	4	14	62	5
Severely T.H.	5	5	3	5	72	9
U.S. in general 1975	41	7	17	18	10	7

*Reference 51.

TABLE 1-13. CHARACTERISTICS OF WHEELCHAIR USERS*

	Non-Motor (%)	Motor (%)	All (%)
Unable to use taxi	29	67	36
No trouble getting places	10	2	8
Getting off or on bus is a serious to impossible problem	95	100	96
Serious or impossible problem to go three blocks	41	29	39

*Reference 51.

TABLE 1-14. MOST NEEDED BUS ADAPTATIONS CLASSIFIED BY MAJOR HEALTH PROBLEM*

Impairment	Number of Persons Interviewed	Desired Changes
Arthritis	143	Lower step (67%); Driver waits until seated (57%)
Blindness	179	Announce stops (75%); Driver waits (53%)
Cerebral palsy	148	Lifts on buses (64%); Assistance (47%)
Heart problems	49	Driver waits (53%); Announces stops (45%)
Orthopedic	222	Driver waits (62%); Lower step (57%)
Spinal cord injury	83	Lifts (89%); Curb cuts (34%)
Stroke	83	Driver waits (67%); Assistance (62%)
Mental retardation	59	Announces stops (64%); Driver waits (51%)
Old age	86	Lower step (59%); Driver waits (38%)

*Reference 51.

From these data it becomes apparent that there is no "typical handicapped person." The data show that the needs of transportation handicapped people are diverse. However, it appears that by addressing the needs of passengers in wheelchairs and those in side facing seats, many of the transportation handicapped people are covered.

1.2.4 Past and On-Going Government Agency Research Programs

The Department of Transportation and its agencies have sponsored a number of study programs to investigate the transportation needs of handicapped and elderly persons. These studies both provided data on buses and systems presently being used and recommended buses and systems that should be used. A complete

bibliographic listing is included at the end of this report. This subsection reviews some of the study reports and sketches the data obtained from them.

- "Study of Future Paratransit Requirements – Final Report" (Reference 52), January 1977, studied selected characteristics of 10 small buses (Table 1-15).

- "Bus Characteristics Needed for Elderly and Handicapped in Urban Travel" (Reference 53), March 1976, – compared and described five small bus systems for the elderly and handicapped (Table 1-16).

- "Transportation Problems of the Transportation Handicapped" (Reference 54) mentioned the Totally Accessible Elderly and Handicapped Transporter marketed by FMC. It also pointed out that most handicapped transportation systems presently in use are special dial-a-ride vans or taxis, or some type of demand-responsive buses.

- "Small Transit Bus Requirements Study" (Reference 55), December 1976, determined "general and performance specifications for an advanced small urban transit bus." The report gave the average loading and unloading times for wheelchair lift equipped buses used in Denver, Colorado, and Gothenburg, Sweden. Average loading times for the two lift systems were 2 minutes, 41 seconds, and 4 minutes, 50 seconds, respectively. Unloading times were 1 minute, 15 seconds, and 2 minutes, 24 seconds, respectively. Both are demand-responsive small bus systems. A subsequent March 1977 report (Reference 21) contained the data shown in Table 1-17.

- "A Study of Wheelchair Access to the Current Transit Bus Design" (Reference 56), April 1977, listed not only present conditions in transit systems, but also some design parameters for wheelchair access. Most buses presently in use have the same basic problems: the floors are too high (33 to 35 inches) and the doors and aisles are too narrow (approximately 30 inches). For wheelchair access, 38 inch wide doors and aisles are recommended. The study found that about 15 percent of the wheelchairs used have extreme or odd dimensions, but 85 percent could be accommodated by designing for the dimensions shown in Figure 1-30.

TABLE 1-15. SELECTED CHARACTERISTICS OF SMALL BUSES

Bus	Number of Passengers				Entrance Characteristics		
	No Wheelchair Station		With Wheelchair Station(s)				
	Seated	Standing	Seated	In Wheelchair	Floor Height (inches)	Number of Steps	First Step Height (inches)
Steyr City Bus	14	14	*	*	12	1	12
Mercedes 309 D	16-19	*	10	2	32.4	3	15
Battronic Electric AMV 147	22	11	*	*	32.6	3	13
Grumman 17-19	17-19	*	Optional	Optional	32.5	3	11/13.5
Rohr/Flxible Flxette	19-23	*	Optional	Optional	30	3	14
Airstream Argosy CB-22	19	*	*	*	*	3	9.5
RI-GMC Transmode Transporter	18-20	0	Optional	Optional	16.2	2	8.5
UTDC Small Bus	17-24	*	7	5	30	3	13.5
Twin Coach TC-HD-25	25	13	Optional	Optional	30	3	14
FMC Transit Coach	26-28	*	12	4	18.5	23	11.5/6.5

*The data were not specified in the brochures. Data taken from report published in January 1977.

TABLE 1-16. ELDERLY AND HANDICAPPED BUS SYSTEMS COMPARED

System	Characteristics								
		Seating Capacity							
	Type of Bus	No. Buses	Wheelchairs	Seated Passengers	Lift	Wheelchair Restraints	Seats	Entrance	Floor Height (inches)
Tote (St. Petersburg, Florida)	Dodge Maxivans, raised roof	2 13	1 0	9 13	Hydraulic lift in rear operated from outside	Seatbelt across chair, plus plastic encased chain lock on wheel (not used)	Perimeter padded seats with belts	---	---
Handy-Ride, Regional Trans. District (Denver, Colorado)	FMC Coaches	All	4	10	Hydraulic lift on side door	Floor-mounted stand with manual wheel clamp	Padded perimeter bench seats	2 parallel side doors, one with lift, one with hydraulic extended lower step less than 7" off ground	18
Call-A-Bus (Syracuse, New York)	1974 Mercedes 309 Buses	All	2	10	Hydraulic lift, side door internally operated	Air activated piston restraint on wheel, also seatbelts	Parallel and transverse seats	2 parallel side doors, one with extending lower step 9" high, other with lift	---
Toronto Schools - U.C. Elementary Students	UTDC Buses (also regular school buses and van	---	12	6	2 step entry converts to wheelchair lift platform, internal or external control	Belt across lap and across bottom of wheelchair frame attached to wall	Benches over rear wheelwells	Single side entrance	---
Special Transportation System (Gothenburg, Sweden)	Mercedes	---	3	10	Hydraulic lift in rear	4-point strap tiedown	Single, front facing seats	---	---
	Peugeot	---	0-2	4-10	Pullout ramp in rear	4-point strap tiedown	Bench seats or special parallel compartments for handicapped		

TABLE 1-17. CHARACTERISTICS OF URBAN BUS SYSTEMS

CHARACTERISTICS	NUMBER OF BUSES
Total U.S. transit buses	48,700
Number included in survey	24,254
Breakdown of buses surveyed:	
Less than 40 passengers (small size)	1,060 (4.4%)
More than 40 passengers (full size)	23,194 (95.6%)

PASSENGER LOADING

31-35 peak
11-15 off peak

SEATING CAPACITY

	SEATS OCCUPIED		
	Peak	Off Peak	
11-20	39%	42%	(relative use of different size buses in fixed route service)
21-30	26%	31%	
31-40	25%	23%	

TYPICAL URBAN FIXED ROUTE PROFILE	
Stops per mile	10
Maximum speed	20 mph
Initial acceleration	3 mph/sec (4.4 ft/sec^2)
Average deceleration	4.1 mph/sec (6 ft/sec^2)
Stopped time	10 sec per block
Running time	24.6 sec per block
Block speed	10.4 mph
Running speed	14.6 mph
Mileage	83 miles per 8-hour shift

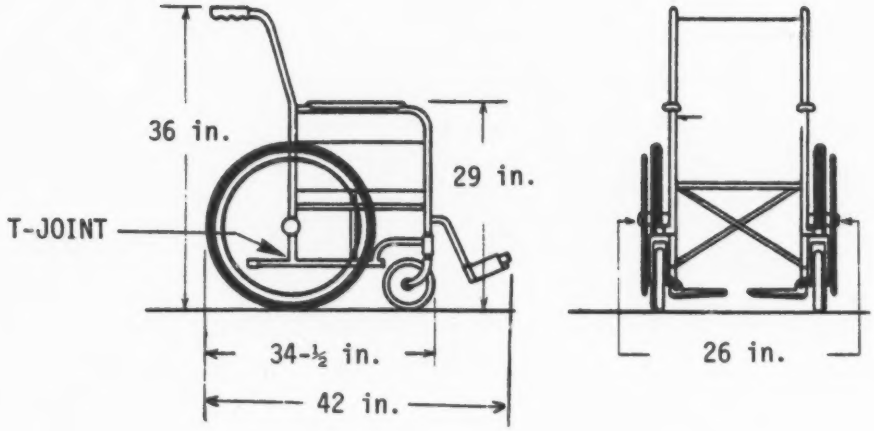


FIGURE 1-30. TYPICAL WHEELCHAIR DIMENSIONS

In this study (Reference 56) the authors found that the width of a standard bus (96 inches) does not allow sufficient space for interior maneuvering, especially in the wheel housing area. Wider buses (102 inches), such as the A.M. General, were deemd to be reasonably convenient for entering, reaching the fare box, and turning down the aisle in a wheelchair.

The report also discussed wheelchair lock systems, most of which are manually operated. These systems clamp automatically when the wheelchair is backed into them, but they must be manually released by exerting a 5 to 10 pound force on the handle. Generally only one wheel is locked. The lock systems have several drawbacks: they

- Require considerable dexterity and strength (to reach backward and push the release handle)
- Can damage the locked wheel and spokes
- Do not hold the wheels, and therefore do not provide sufficient security
- May be hazardous to the feet of passengers in the seat behind, because the clamping device is often mounted on the bottom of a fold up seat.

The report states that lap and shoulder belts are needed in addition to the wheel lock system.

The lift devices included in the study were the dual-purpose type designed for use in the conventional transit bus entry. Although five were reviewed, three were still in the concept stage, one was a prototype, and only one was actually in production. These are described in Table 1-18. The study also investigated the applicability of the lifts to current transit buses: the A.M. General bus was considered representative. It was found that the door could only be widened to 34.6 inches (not the preferred 38 inches) without structural changes, but that a stepwell lift could be installed without significant impact on structure or design.

TABLE 1-18. LIFT DEVICES

Designer/ Manufacturer	Description
Environmental Equipment Corporation	Diagonal platform under stepwell that comes out to curb; steps unfold to provide secondary platform to lift from lower platform to bus floor (still in concept stage).
Para Industries	Steps articulate into platform; platform moves from ground level to floor level (still in concept stage).
Mr. Hall	Lower step extends under second step, moves out to form platform, and rises to floor level; second step remains in place (still in concept stage).
Sheller-Globe	Second step folds out of the way and the rest of the stepwell becomes platform which lowers and raises (one unit in prototype stage).
Transportation Design and Technology	Both steps deployed to make lift platform; hydraulically driven; loading edge has pressure-sensitive tape that halts it on contact with ground (or wheelchair, etc.); manual hand pump in case of system failure (in production).

• "Design, Test, and Development of a Wheelchair Restraint System for Use in Buses" (Reference 57) described the typical restraint systems in use as those that attach the rear wheels of the wheelchair to the side wall of the bus with the handicapped passenger facing inward. In some cases a loose-fitting belt, nominally anchored to the side wall of the bus, is used to restrain the upper torso from falling forward (inward) when the bus is cornering or swerving. In most cases, the wheelchair securement is weakly attached to the bus sidewall and, to their knowledge, none of the existing wheelchair securement devices had been evaluated in actual or simulated bus collisions.

The criteria used to develop the restraint system designed in the study were that a wheelchair-seated passenger should survive a 30 mph frontal impact and a 15 mph rear impact. No exact specifications were established for side impacts or rollovers. However, such impacts were considered in the design. The restraint system developed was composed of a rearward facing, vertical restraint couch to provide passenger and wheelchair protection in severe front-end collisions, a three-point seat belt system, attached to the framework of the restraint couch, not to the wheelchair, to provide passenger restraint in rear-end collisions (and in rebound from front-end collisions), and a cable system securing the wheelchair to the base of the framework of the restraint couch. The cable mechanism is spring-operated; it attaches to the wheelchair as the wheelchair is backed in and is released by a bicycle gearshift mechanism attached to the side wall. The cable mechanism does not require an unusual amount of strength or dexterity.

• "Safety Considerations in Design of New Transit Bus" (Reference 58) reported the injury-causing aspects of present conventional seats, and the test results for the three new cantilevered seats designed (by three different companies) for the Transbus project. The faults found in the present systems were:

- The horizontal grab bars along the tops of seat backs do not serve as well as vertical stanchions for support in standing, walking or holding on during an (obviously minor) accident, and are a hazard to passengers seated behind them.
- Seats that face a large open area need restraining barriers.
- Side facing seats should be bucket shaped and have padded armrests.

- Slippery seat materials, such as fiberglass, do not hold passengers in place as well as upholstery does.

The three Transbus seats were subjected to sled tests and were reported to be satisfactory in containing passengers safely during test crashes. Some seat characteristics were:

- The seats do not have legs; all forward facing seats are cantilevered from the walls.
- The tops of the seat backs (forward facing seats) have crash pads combined with the handrails.
- The side facing seats have high seat dividers.

• "Structure Verification of Bus Passenger Seats" (Reference 59) reported on a project undertaken to evaluate proposed seat structure criteria. The criteria specified that seats meet certain load/deformation specifications. The seats were then constructed and tested according to the criteria. A steel tubing seat structure is shown schematically in Figure 1-31, where the seating reference point is shown with respect to the seat structure.

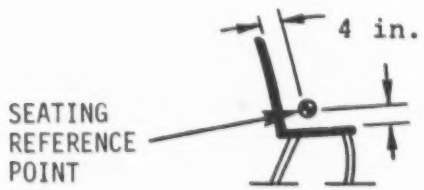


FIGURE 1-31. BASIC SEAT STRUCTURE

The report concluded that seats can be made to pass the given static load requirements (similar to FMVSS 222) but that impact requirements should also be established.

• "Wheelchair Securement on Bus and Paratransit Vehicles" (Reference 60), is an on-going Minicars program. The work is supported by an UMTA grant through a contract with the State of California, Department of Transportation (Caltrans).

The wheelchair securement program has been conducted simultaneously with this program. Consequently, both programs have received the benefit of an interchange of ideas, data and test results. The Caltrans-UMTA program includes

- Static load-deflection tests of wheelchairs
- Dynamic sled tests of wheelchairs with anthropomorphic dummies
- Correlation of the dynamic and static tests and the analytical results.

The details of the program are documented by Caltrans in their Interim Report (Reference 60). The results are briefly summarized below.

- Static Tests. Figures 1-32 and 1-33 show the results of the static load-deflection tests of a wheelchair structure. In an additional test a wheelchair wheel was secured with a pin. The results showed that the capability of that setup was limited to a lateral load of 2 Gs (with an occupant weight of 165 pounds).

- Dynamic Tests. A total of 42 sled tests were conducted during the course of this program. The parameters investigated are listed below:

  - Size and type of wheelchair. Most of the tests were conducted using the Everest and Jennings manual wheelchair Model P8AU(260)(770). A few tests were conducted using the Everest and Jennings powered wheelchair Model P8AU(200)(32770).
  - Anthropomorphic dummy. A 50th percentile adult male dummy was used in all the tests.
  - User restraint system. All of the tests were conducted with the wheelchair seated dummy restrained with conventional automotive belt restraint systems. The first five tests were conducted with a belt that went over the dummy's midsection and looped around the wheelchair seat back. The next three tests had a lap belt secured to the floor behind the wheelchair. The remaining tests were conducted with a lap belt attached to the insides of the

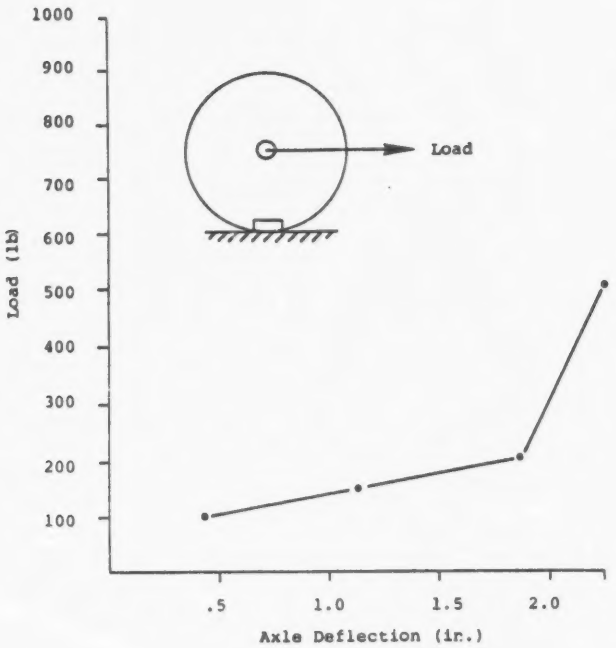


FIGURE 1-32. WHEELCHAIR WHEEL LOAD-DEFLECTION CHARACTERISTICS FOR LONGITUDINAL LOADS

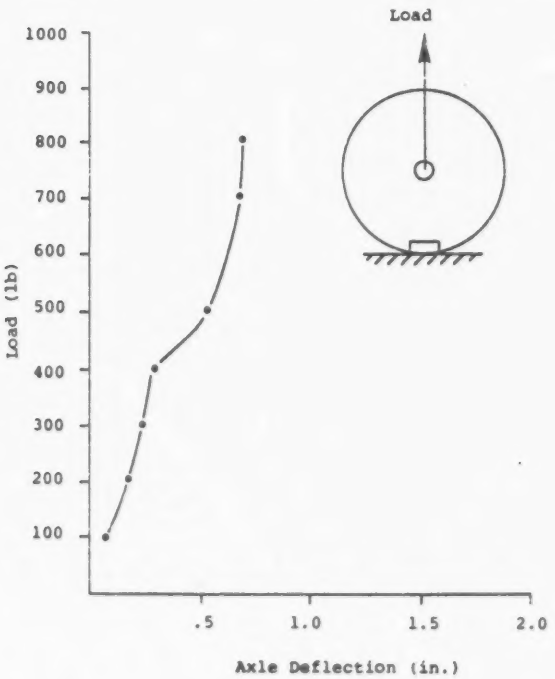


FIGURE 1-33. WHEELCHAIR WHEEL LOAD-DEFLECTION CHARACTERISTICS FOR VERTICAL LOADS

wheelchair axle bolts; the belts then ran underneath the armrests, crossed over the hipjoint area and latched in the dummy's lap.

- Wheelchair securement systems. The wheelchair securements used (Table 1-19) were, in most cases, a generic representation built by Caltrans of the off-the-shelf, readily available hardware.
- Wheelchair orientation. All tests simulated a frontal impact. The wheelchair orientation was either forward facing or side facing, with the one exception of the Wayne State rear facing system.
- Sled speed and deceleration level. Most tests were conducted with sled speeds of approximately 20 mph and deceleration pulse of about 10 Gs amplitude and 100 msec duration. The actual speeds and deceleration levels are identified in Table 1-19.

The results of all of the sled tests are shown in Table 1-19.

- Correlation of Dynamic - Static Tests and Analytical Test Results. This part of the program has not yet been completed, but, based on the test programs, Caltrans outlined a number of suggested improvements in hardware. The suggestions are restricted to minor changes which the authors believe can significantly improve a securement system's effectiveness in securing a chair and its occupant during a crash.

- Wheelchair. By and large, the wheelchairs tested were much stronger in some crash situations (for instance, forward facing during frontal impacts) than originally had been anticipated. Still, various parts of the chairs could be strengthened, at modest cost, to improve their crashworthiness in those situations.

  Several failures occurred in the seat fabric reinforcement. When the dummy was secured by a belt attached to the rear wheel axles, seat failure caused greater dummy excursion than would have occurred had the seat not failed. Hence, the prevention of seat edge tear-out would

TABLE 1-19. SUMMARY OF DYNAMIC TEST RESULTS (REFERENCE 60)

Systems Tested & Facing Direction	Test No.	Sled Speed (mph)	Sled Deceleration (Gs)	Chair Type	Footrest Type	Seat Belt	Seat Belt Load (pounds)	Head Excursion (inches)[1]	Dummy Strike	HIC[2]	CSI[3]	Chair Damage	Comments (See Note)
T-Bar (Front Position)													
Forward	1040	9.0	6	Manual	Rigid	Loop to chair back	NA	54	NE	0	0	Minor bending of front casters, footrest & back parts.	4
	1045	20.3	12	Manual	Rigid	Loop to chair back	NA	69	NE	NA	22	Minor bending of front casters & footrest. Major bending in back parts.	4
	1116	5.7	10	Manual	No footrest	To axles	NA	41	NE	0	0	None.	4
	1117	11.7	10	Manual	No footrest	To axles	NA	60	NE	NA	NA	Minor caster bending.	4
	1060	19.3	12	Manual	Rigid	To axles	900	56	NE Head on legs	172	86	Minor bending in front casters & frame.	4
	1095	19.7	12	Manual	No footrest	To axles	700	61	NE	106	38	Major damage to front casters. Bottom left rail bent.	5

LEGEND: NA = Not Available; NE = No Envelope provided; NR = Not Relevant (securement failed; therefore, results are not applicable)

NOTES: (1) Forward, relative to pretest position. (2) Head Injury Criteria. (3) Chest Severity Index. (4) T-bar slid off caster arch. (5) Chair tipped forward approximately 90 degrees.

TABLE 1-19. (CONT'D)

Systems Tested & Facing Direction	Test No.	Sled Speed (mph)	Sled Deceleration (Gs)	Chair Type	Footrest Type	Seat Belt	Seat Belt Load (pounds)	Head Excursion (inches)[1]	Dummy Strike	HIC[2]	CSI[3]	Chair Damage	Comments (See Note)
	1041	7.7	5	Manual	Rigid	Loop to chair back	NA	30	NE	2	0	Minor bending in the leading caster fork stem.	4
	1074	17.2	12	Manual	Rigid	To axles	400	71	NE	54	10	Major damage to leading caster. Minor damage to trailing bottom rail.	5
T-Bar (Rear Position													
Forward	1077	19.9	12	Manual	Rigid	To axles	NA	41	NE Head on legs	250	62	Moderate damage to side frame, casters & footrests.	6
	1118	20.0	12	Manual	No footrest	To axles	1100	NR	NE	138	28	Not relevant.	7
Side	1122	19.3	12	Manual	Rigid	To axles	NA	54	NE Head on arms	310	NA	Major damage to leading side (wheels & frame)	8
Wall Rim Pin													
Forward	1063	19.3	12	Manual	Rigid	To axles	1200	45	NE	172	40	Minor damage to rear wheel rims.	9
	1100	23.2	12	Manual	No footrest	To axles	1100	43	NE	322	76	Major caster & rim damage.	10
	1101	23.1	12	Manual	Rigid	To axles	NA	46	NE	190	60	Failure of the spokes led to major rear wheel rim damage.	11

LEGEND: NA = Not Available; NE = No Envelope provided; NR = Not Relevant (securement failed; therefore, results are not applicable)

NOTES: (1) Forward, relative to pretest position. (2) Head Injury Criteria. (3) Chest Severity Index. (4) Chair rotated approximately 10 degrees. (5) Chair tipped forward. (6) Chair tipped forward slightly. (7) Anchor bolt failed; chair unrestrained. (8) Violent impact of dummy and armrest. (9) Rear wheels lifted off the floor several inches. (10) Chair tipped forward approximately 90 degrees. (11) Same as Test 1063.

TABLE 1-19. (CONT'D)

Systems Tested & Facing Direction	Test No.	Sled Speed (mph)	Sled Deceleration (Gs)	Chair Type	Footrest Type	Seat Belt	Seat Belt Load (pounds)	Head Excursion (inches)[1]	Dummy Strike	HIC[2]	CSI[3]	Chair Damage	Comments (See Note)
Wall Rim Pin													
Side	1073	11.3	9	Manual	Elevating leg rest	To axles	300	44	NE	8	2	Minor damage to a caster, a rear wheel & X-brace	
	1072	19.4	12	Manual	Rigid	To axles	1000	61	NE	44	24	All spokes failed on trailing wheel. Major damage to most parts.	4
Floor Rim Pin													
Forward	1054	19.0	12	Manual	Rigid	Loop to chair back	450	53	NE	20	10	Major bending in back posts. Minor bending in frame & wheels.	5
	1059	19.1	12	Manual	Rigid	To axles	1300	44	NE	158	40	Major damage to wheels & casters.	
Side	1055	19.0	12	Manual	Rigid	Loop to chair back	300	56	NE	70	18	Major damage to wheels, casters & frame.	6
	1087	10.3	10	Manual	Elevating leg rest	To axles	450	38	NE	14	2	Minor damage	
	1070	18.5	12	Manual	Rigid	To axles	NA	56	NE	46	16	Major damage to wheel parts.	7
Fender													
Forward	1064	19.5	12	Manual	Rigid	To axles	1000	48	NE	NA	NA	Severe bending in rear wheels. Casters bent aft 1 inch.	
Side	1071	19.5	12	Manual	Rigid	To axles	1300	39	NE	186	34	Moderate damage.	8

LEGEND: NA = Not Available; NE = No Envelope provided; NR = Not Relevant (securement failed; therefore, results are not applicable)

NOTES: (1) Forward, relative to pretest position. (2) Head Injury Criteria. (3) Chest Severity Index. (4) Violent impact between dummy and armrest. (5) Belt in contact with upper abdomen. (6) Securement did not confine dummy. (7) Although the chair was destroyed, the dummy was held. (8) Violent impact between dummy and armrest.

TABLE 1-19. (CONT'D)

Systems Tested & Facing Direction	Test No.	Sled Speed (mph)	Sled Decel-eration (Gs)	Chair Type	Footrest Type	Seat Belt	Seat Belt Load (pounds)	Head Excursion (inches)[1]	Dummy Strike	HIC[2]	CSI[3]	Chair Damage	Comments (See Note)
User and Chair Belt													
Forward	1079	19.8	12	Manual	Elevating leg rest	To floor	2000 (failed)	64	NE Head on legs	500	74	Not applicable.	4
	1086	22.2	12	Manual	Rigid	To floor	2400	NA	NE Head on legs	424	68	Minor front damage.	
	1099	22.5	12	Manual	No foot-rest	To floor	2400	50	[illegible] legs	1338	124	Seat tore & cross frame bent.	
Side	1078	11.5	10	Manual	Elevating leg rest	To floor	650	44	NE Of test room wall	NA	NA	Minor bending in leading wheel & bottom frame	5
	1098	10.5	12	Manual	Rigid	To floor	900	44	NE	8	4	Leading wheel badly bent.	6
Three-Point Belt													
Forward	1183	20.1	12	Manual	Rigid	To axles	450	50	Head on legs	306	[illegible]	Seat tore & cross frame bent.	
Side	1184	20.1	10	Manual	Rigid	To axles	850	52	Head on obstruction armrest	1532	158	Major damage to side frames & right rear wheel. Seat tore.	7
Horizontal Bars													
Forward	1185	20.0	10	Manual	Rigid	To axles	NR	[illegible]	NR	NR	NR	Not relevant	8
Side	1186	19.9	12	Manual	No foot-rests	To axles	NR	NR	Head & hand on obstruction	NR	NR	Not relevant	9

LEGEND: NA = Not Available; NE = No Envelope provided; NR = Not Relevant (securement failed; therefore, results are not applicable)

NOTES: (1) Forward, relative to pretest position. (2) Head Injury Criteria. (3) Chest Severity Index. (4) Belt broke; dummy and chair unconfined. (5) The usual wall behind the chair was not provided. (6) Back wall provided. (7) Head blow probably fatal. (8) Securement released. Backup belt system restrained chair. (9) Anchors slid sideways allowing back-up belts to restrain chair.

TABLE 1-19. (CONT'D)

Systems Tested & Facing Direction	Test No.	Sled Speed (mph)	Sled Decel-eration (Gs)	Chair Type	Footrest Type	Seat Belt	Seat Belt Load (pounds)	Head Excursion (inches)[1]	Dummy Strike	HIC[2]	CSI[3]	Chair Damage	Comments (See Note)
Modified Horizontal Bars													
Forward	1191	20.0	10	Electric power	Rigid	To axles	500	43	Left hand on stanchion; right hand on obstruction armrest	352	56	Moderate bending & crushing of armrest.	4
Side	1193	20.0	10	Electric power	Rigid	To axles	1200	58	Head on seat cushion; head on armrest; elbow on ???	286	90	Right armrest & wheel bent. Extensive bending & twisting in frame.	5
Single Rim Latch													
Forward	1187	19.8	11	Manual	Rigid	To axles	NR	NR	NR	NR	NR	Not relevant	6
	1196	19.9	10	Electric power	Rigid	External lap & shoulder	1400	34	Head on right leg	622	124	Backpost bent aft. Seat separated from back.	7
Modified Single Rim Latch													
Forward	1197	19.9	10	Manual	Rigid	To axles	180	54	Shoulder stanchion; knees on seat	128	98	Right rear wheel deployed.	8

LEGEND: NA = Not Available; NE = No Envelope provided; NR = Not Relevant (securement failed; therefore, results are not applicable)

NOTES: (1) Forward, relative to pretest position. (2) Head Injury Criteria. (3) Chest Severity Index. (4) Securement bar held through impact, but dropped off on rebound. (5) Extreme lateral torso rotation. (6) Securement released. Backup belts restrained chair. (7) Wheel lock unlatched. Shoulder belt ineffective. Improper retractors. (8) Excursion limited by shoulder impact.

TABLE 1-19. (CONT'D)

Systems Tested & Facing Direction	Test No.	Sled Speed (mph)	Sled Decel-eration (Gs)	Chair Type	Footrest Type	Seat Belt	Seat Belt Load (pounds)	Head Excursion (inches)[1]	Dummy Strike	HIC[2]	CSI[3]	Chair Damage	Comments (See Note)
Wayne State													
Rear	1189	20.0	9	Electric power	Rigid	External lap & shoulder	50	14	Head on securement cushion	144	68	None	
Forward	1190	20.0	10	Electric power	Rigid	External lap & shoulder	460	24	None	72	58	Backposts bent aft.	4
Cross Brace Belt													
Side	1199	19.9	10	Manual	Rigid	To axles	1100	54	Right arm on obstruction armrest	130	68	Major damage to frame. Cross brace failed.	5
Frame Cable													
Forward	1201	20.0	9	Manual	Rigid	To axles	370	NR	Shoulder on stanchion; legs on seat	70	80	Minor bending in back posts & cross brace	6
Frame Anchor													
Forward	1235	20.0	10	Manual	Rigid	To axles	300	39	Legs & hands on obstruction; head on arms & legs	306	NA	Seat attachment failed. Moderate bending in frame & caster	

LEGEND: NA = Not Available; NE = No envelope provided; NR = Not Relevant (securement failed; therefore, results are not applicable)

NOTES: (1) Forward, relative to pretest position. (2) Head Injury Criteria. (3) Chest Severity Index. (4) Chair cable failed, transferring load through dummy. (5) Violent impact between dummy and ostruction armrest. (6) Cable failed, releasing chair and dummy.

greatly improve the chairs' performance for the occupant by minimizing his excursion.

Strengthening the rear wheels would improve the overall performance of those securement systems which attach to the rear wheels. On the other hand, the wheels can not be strengthened significantly without excessive cost and probably added weight. Even so, securement systems which attached to both wheels performed satisfactorily in forward facing frontal impacts. From the excessive damage the wheels suffered in most crashes with side facing chairs, it appears that considerable strengthening would be required before their resistance to lateral loading would be significantly improved. Therefore, wheel strengthening was not suggested.

- T-bar. Improvement in the T-bar system can be made by restricting its attachment to the lowest horizontal frame member, either just forward of the chair's cross brace or just forward of the chair's backpost (the backpost position provides the greatest protection during frontal crashes). It appears that further improvement can be made by providing generous-length, upside down U-shaped brackets (on the ends of the T-arms). Generous lengths in bracket legs provide greater assurance of containing the chair during crash rebound and secondary crashes.
- Wall rim pin. When the wall rim pin system is used for forward facing wheelchairs, it should include a means to restrict lifting and upward rotation of the rear wheels. The need for restricting wheel movement is especially important when rigid footrests are not part of the wheelchair being secured.
- User and chair belt. For best performance during a crash, the chair should be backed up to a wall (as opposed to just providing "stops" for the rear wheels) when the user and chair belt system is used.
- Horizontal bars. The attachment hooks of the horizontal bar system can be attached anywhere along the chair's forward vertical frame members, or the forward part of the armrests. If

they are placed below the axles of the chair's large wheels, there will be a tendency for the chair to overturn. Therefore, the hooks should be attached above the axles, preferably above the combined center of gravity of the wheelchair and user. Likewise, the anchoring mechanism for the horizontal bars should also be located above the axles.

The attachment hooks must be sufficiently strong to prevent them from straightening during impact, and must be designed so that they maintain attachment during postcrash action.

The anchor mechanism for the bars requires a "stop" attachment to prevent undesirable sliding along the mechanism when the wheelchair is facing sideways in a frontal impact.

- User belt system. Belts attached to the vehicle should have locking type retractors. Non-locking spring reel retractors do not provide proper securement without careful adjustment. Inertia locking retractors may provide securement during sudden stops and crashes, but they are ineffective for restraining the movement of a wheelchair during the normal stopping and turning activities of the vehicle. It is therefore recommended that inertia locking retractors not be used for wheelchair securement. If shoulder belts are provided, they should be coupled with the hip belts in a manner that positions the belt diagonally across the upper torso of the user.

- Summary of Findings from the Caltrans Tests. The effectiveness of the restraint system was assessed on the basis of occupant excursion, taken as the sum of three components:

  - Forward rotation of the occupant about his hip joint to the horizontal position
  - Forward translation of the hip joint with respect to the chair's rear axles and the seat belt anchors
  - Forward translation of the rear axles with respect to a fixed reference point.

Based on the results of tests, it was concluded that:

- If the seat belt is anchored to the chair frame, all restraint systems perform similarly in terms of forward head excursion.
- The simple seat-back looped seat belt is inadequate for occupant containment.
- A forward T-bar position allows unsatisfactory slippage and inclination of the T-bar tension member, resulting in excessive occupant excursion.
- The point of attachment of a securement system to a wheelchair and the direction the chair is facing with respect to the direction of impact are the important variables in the crashworthiness of the chair.
- The wheelchair in general is capable of absorbing higher impact energy than originally thought by most people involved in transportation of the handicapped.
- A rearward facing wheelchair with padded head and torso restraint provides good protection in frontal impacts if the wheelchair is properly secured.
- To provide good protection in frontal impacts, a forward facing wheelchair must be properly secured, the occupant properly restrained and injury-producing hardware removed from the occupant excursion zone.
- A side support (wall or seat back) increases the chair's ability to withstand impact loads perpendicular to the direction that the wheelchair is facing.
- Systems that rely on tension for attachment can become free when the chair deforms and the system rebounds. Consequently, such systems must have supplemental methods of maintaining contact with the chair during post-impact action.
- Securement by a belt around the user's waist and the back of the chair is unsatisfactory (because of the high potential of internal injury). Improved securement can be obtained by the use

of a lap belt which passes over the hip area and is secured at the axles.

- Occupant excursion varied widely in the systems tested. The availability of a clear envelope and the removal or padding of obstructions should be of prime concern in the selection and placement of a securement system.

- A test program sponsored by the Veterans Administration at Texas A&M University (Reference 61) investigated the performance of wheelchair securements in vehicles under normal operating conditions. The conditions considered were severe braking, bumpy roads, sharp cornering and combinations of the three.

- An NHTSA-sponsored research program at the University of New Mexico (Reference 62) dealt with the retrofitting of school bus seats to meet the requirements of FMVSS 222.

- ASL Engineering, Inc. (Reference 63) completed a study which researched energy absorbing materials for occupant protection padding in school buses. Some on-going programs contributed to the considerations and guidelines that were used in the selection of components and systems that were tested in full scale crash tests.

1.2.5 Personal Interviews

1.2.5.1 School and Transit Bus Operator Comments

To observe how special equipment is used, Minicars personnel arranged to ride on two "orthopedic school buses" operated by The Bus Company, Goleta, California. The following paragraphs present comments made by the drivers of these buses (Reference 64).

Bus Size

Although the comments obviously do not constitute a representative sample, we think that the points made by the two drivers have merit and are important for the present study. For these reasons we are including them in this report.

The drivers indicated that they preferred midsize to either small or large buses. They rejected small van type buses because of their very limited head room and the confined space in which to maneuver wheelchairs. Their objections to large school buses were that they are difficult to maneuver in residential areas, narrow streets and cul-de-sacs, and that the ones with more wheelchair stations are usually placed on long routes.

Lifts

The school bus drivers felt that a side-mounted lift is more convenient and safer than a rear entry lift, because the bus can stop at the driveway or curb. When the door is at the rear of the bus, the wheelchair has to travel into the street, at times moving the whole length of the bus. They mentioned that one particular lift has to be pulled down to the horizontal position and stowed manually. This lift is fairly heavy and much more tiring to use all day than is the fully automatic lift.

Other Comments

The two school bus drivers mentioned that the buses are often not filled to capacity. A bus with a maximum capacity of nine wheelchairs generally picks up only five or six wheelchairs, to avoid crowding. Wheel pin locks mounted to the wall are fine if they fit the wheel width, but wheelchairs vary quite a bit, and non-adjustable wheel locks are almost useless. In the opinion of the two drivers, straps attached only to the floor (e.g., the four cargo tie-downs that attach to four points of the wheelchair) are not as good as two attachments on the floor and two on the wall. (During the week before our interview, a wheelchair tied down in that fashion had tipped over and collapsed while the bus was going around a corner.)

The school bus drivers thought it would be helpful to have some non-handicapped children on the bus to aid the handicapped children (especially in emergencies). Electric wheelchairs can be as easy to handle as manual ones, but some have the small, solid wheels that are difficult to maneuver over bumps. There also is

great diversity in wheelchair sizes and shapes, as well as in the wheelchair passengers' abilities, needs and sizes. Both drivers said that there was little trouble with wheelchair passengers becoming ill from riding sideways or backwards.

We also obtained information from Messrs. T. Martin and G. Larsen (Sales and Management, respectively) of The Bus Company (Reference 65). Again, they hardly constitute a representative sample -- but we thought their comments sufficiently important to be worth reporting.

For handicapped pupils The Bus Company uses Dodge Maxi-Vans and midsize buses. Vans can hold four wheelchairs and have either a side ramp or a rear-mounted lift. The comments and observations included:

- The cheaper lifts resulted in maintenance problems, attendant downtimes, and additional costs. A more expensive design proved to be trouble-free in operation and hence more cost effective.
- Non-wheelchair seating problems begin with junior high school students. Buses transporting these students meet the FMVSS 222 21-inch maximum distance requirement for seat spacing, but the legroom is inadequate for the larger children.
- Manual override systems on lifts are necessary for emergency situations.
- Vans (as delivered from the manufacturers) can no longer be used for school buses. They must be modified to meet seat, rollover and joint strength requirements. Headroom must be increased, or the ceiling padded.
- They indicated that, per their experience, van conversion buses are more common than the specially built buses, primarily because of cost.
- Door-to-door service is, they feel, the proper way to transport handicapped pupils (rather than picking them up at designated bus stops).

- They feel that, on school buses, drivers should supervise and assist children in securing restraint systems, since the bus operator has the ultimate responsibility for the children's safety.
- Of the various tie-downs used by The Bus Company, cargo tie-downs were stated to be the most convenient.
- California state law requires that 3/8-inch bolts be used in any attachment of a safety device to the wall. As a result, many bolt stubs project through the side of the bus. The Bus Company representatives consider these protrusions hazardous to people outside the bus.

1.2.5.2 Bus Passenger Comments

Non-handicapped bus riders may be affected by changes in service resulting from accommodating the handicapped. In the Santa Barbara region there are no buses (transit or school) that mix handicapped with non-handicapped passengers, so the reactions of bus riders to such a situation were unavailable. It is reasonable to anticipate that some transit bus passengers will resent inconveniences accompanying wheelchair accommodation on fixed routes. Stops may be longer, or, if seating were not well arranged, wheelchairs could obstruct passage inside the bus.

According to the California Association for the Physically Handicapped (CAPH) members, a person using a wheelchair dislikes being segregated on special buses. They resent being treated as invalids, or as abnormal people.

We elicited comments from the handicapped children picked up on the routes our representatives traveled (again obviously not a representative sample). Two of the comments are noteworthy:

- A child using a wheelchair commented that he did not like riding side facing in a bus because it jostled him from side to side.
- The ambulatory handicapped children, in general, preferred to use seat belts. They felt more secure with the belts than without them.

1.3 USE OF BUS TRANSPORTATION BY THE HANDICAPPED

1.3.1 Demography of the Handicapped Population

In 1970 the total U.S. population was aproximately 203 million, of which approximately 6.6 percent, or 13.39 million, persons were classified as handicapped. Surveys conducted in 1970 estimated that, of the total number of handicapped persons in the U.S., all, except for the institutionalized handicapped, have conditions which may make bus travel difficult. This group represents approximately 12.43 million non-institutionalized handicapped persons. Table 1-20 presents a breakdown of the handicapped by their major handicap. The last column in the table shows 1978 estimates of the transportation handicapped urban population, 5 years of age and over.

TABLE 1-20. HANDICAPPED PEOPLE IN THE UNITED STATES

Condition	Population* (thousands)	Population** (thousands)
Visual impairment	1,970	1,566
Hearing impairment	360	1,572
Wheelchair	430	409
Other aids	5,490	1,938
Other mobility limitations	3,310	3,522
Temporary acute conditions	470	not included
Institutionalized	960	not included
	13,390	7,440***

*1970 Estimates, Statistical Abstract of U.S.A. – 1975 (Reference 66).

**1978 Estimates, UMTA Study (Reference 93).

***Individual categories add up to more than the total because of multiple handicaps.

About one-fifth of a percent of the total population is confined to wheelchairs. (Perhaps a larger percent of bus users would be handicapped, since people with physical disabilities are less likely to drive and own cars.) Of urban workers, about 7 percent are dependent upon transit bus systems to get to work (Reference 67). It would be reasonable to expect that more handicapped people would use transit buses if the buses were better equipped for their needs and if they could get to and from the bus stops.

1.3.2 School Children Population

A statistical survey was performed to establish the physical dimensions and characteristics of the probable school bus population. Data from past and ongoing anthropometry studies (References 68 and 69) were used in conjunction with census statistics on school attendance, grade, age and sex distributions. The results are summarized in Tables 1-21 and 1-22. Data on school age children have been grouped by educational level: Grades 1-6, Grades 7-9, and Grades 10-12. The mean figures for weight and stature are a summary of available data for males, females, and males and females combined. Additional source data used in the survey are contained in Appendix B.

Table 1-23 and Figure 1-34 present data obtained from the Statistical Abstract of the United States, 1975 (Reference 66).

1.3.2.1 Transit Bus Transportation

The general practice has been to use special buses for the elderly and handicapped rather than to provide lifts and safety equipment on standard large buses. However, the recent introduction of DOT response to Section 504 of the Rehabilitation Act of 1973 has resulted in buses equipped for handicapped people on fixed routes in several major cities.

Throughout the country, there are many special bus services oriented to the needs of the handicapped and/or elderly. Several of these services use small buses or van conversions which operate in a demand-responsive manner. As of November 1980, there were almost 5000 standard-sized buses in service or on order with lifts and designated places for wheelchairs.

One such company, the Santa Barbara Municipal Transit District, now has a "HandiTrans" bus (Reference 37) for the handicapped and elderly population which runs on a semi-fixed schedule.* Rides must be arranged 24 hours in advance,

*The service has since been discontinued. The E&H community now is served by Easter Seal Society operated vans on a dial-a-ride basis.

TABLE 1-21. ANTHROPOMETRY PROFILE FOR SCHOOL CHILDREN

Group No.	Grade	Age	Grouped	Sex
A	1	6	6	
	2	7	6	
	3	8	6	0.5094 male
	4	9	6	0.4906 female
	5	10	6	
	6	11	6	
B	7	12	15	0.5086 male
	8	13	15	0.4914 female
	9	14	15	
C	10	15	18	0.5104 male
	11	16	18	0.4896 female
	12	17	18	

TABLE 1-22. SCHOOL POPULATION

Group No.	Male	Female	Combined	Percent Split
Mean stature (inches):				
A	52.14	51.98	52.05	52.06
B	62.03	61.50	61.78	61.77
C	68.30	63.94	66.50	66.16
Mean weight (pounds):				
A	66.51	66.15	66.35	66.33
B	106.88	104.46	105.78	105.91
C	146.30	121.22	134.27	134.02

TABLE 1-23. HANDICAPPED PUPILS IN ELEMENTARY AND SECONDARY SCHOOL, 1970

Condition	Number	Percentage of Total Enrollment
Hard of hearing	131,000	0.30
Deaf	23,000	0.1
Crippled	82,000	0.20
Partially sighted	64,000	0.1
Blind	6,000	0.01
Total percentage		0.71

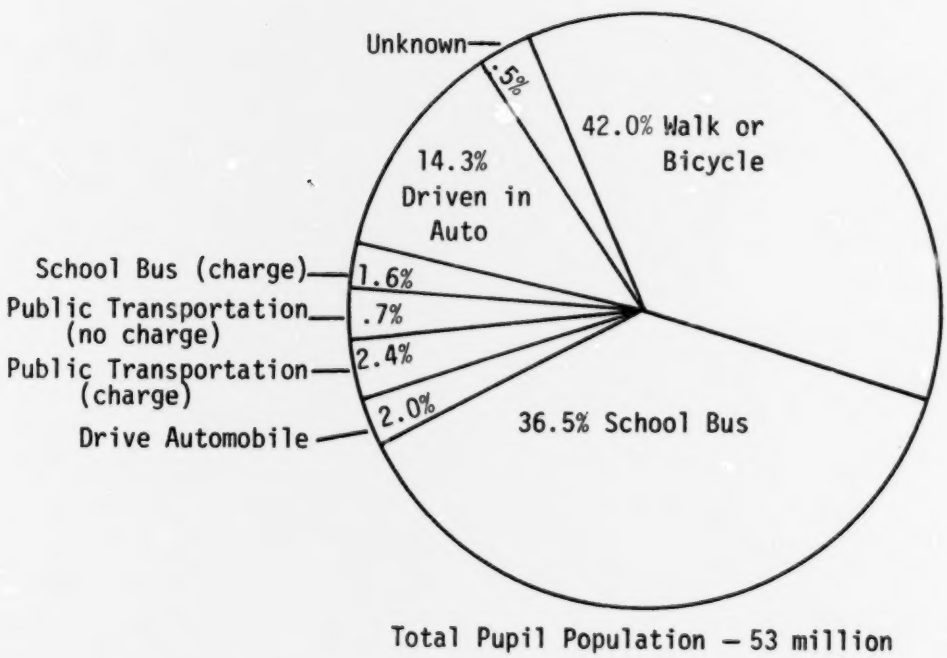


FIGURE 1-34. PUPIL TRANSPORTATION MODES – PERCENT USAGE

and riders must have cards verifying eligibility (specifying they are not able to ride normal buses). The bus is scheduled to go through each of seven zones (Figure 1-35) at certain times each day. This arrangement is fairly typical of the bus services currently available to people with transportation handicaps. The following local organizations serve as a directing board for the Santa Barbara HandiTrans Program. They are currently organizing several additional handicapped transit services to be integrated eventually with the present bus service:

Santa Barbara Department of Rehabilitation
Community Action Commission of Santa Barbara
Muscular Dystrophy Association, Inc.
Santa Barbara General Hospital Memorial Rehabilitation Center
Veterans Memorial Building
Santa Barbara County Mental Health Services
Tri-Counties Regional Center
Easter Seal Society
Center for Community Education
Catholic Social Services.

From recent studies conducted by the DOT and the various transit associations, it appears that some future design objectives (References 52 and 54) are to enable the riders in wheelchairs to conveniently use the normal route buses – though such integrated systems are greatly dependent on the methods and equipment that will make wheelchair loading faster and more convenient. The average loading time (Reference 55) for wheelchairs (e.g., the 2-1/2 to 5 minutes given above for two present systems) would be prohibitive for fixed-route scheduling. The new dual-purpose stepwell wheelchair lifts being designed and produced by several companies would allow more efficient boarding for persons in wheelchairs.

1.3.2.2. School Bus Transportation

Presently, most urban and suburban school districts transport wheelchair-bound and other handicapped pupils in special buses, but rural districts typically put

1 **RIDERS**: *MUST* have a HANDITRANS PASS and *MUST* be shown to driver EACH TIME fare is paid. (One attendant permissible – No Pass necessary .25 fare).

2 **PASS APPLICATION**: Information 962-1217

3 **RESERVATIONS**: Call 962-1217 between 9 a.m. and 2 p.m.; *ONE DAY IN ADVANCE*. Plan your trip before calling. Refer to map for area number and approximate times. Monday reservations must be made on Friday.

4 **RESERVATION PROCEDURE**:
- A. State name and pass number and phone number.
- B. State pick-up address and approximate time.
- C. State destination.
- D. State location and time for return trip.

5 **PICK-UP AT CURB SIDE**: Be ready *15 minutes* before and after pick-up time. Driver will signal arrival (by horn) and will wait three (3) minutes.

6 **CANCELLATIONS**: Notify HANDITRANS IMMEDIATELY! (This is very important!)

7 **EQUIPMENT FAILURE**: Delay of service until repaired. Those riders on route will be assured service. All others on pick-up list will be notified.

EFFECTIVE OCTOBER 17, 1977

HANDITRANS

Santa Barbara METROPOLITAN TRANSIT District

25¢
EXACT FARE

INFORMATION 962-1217

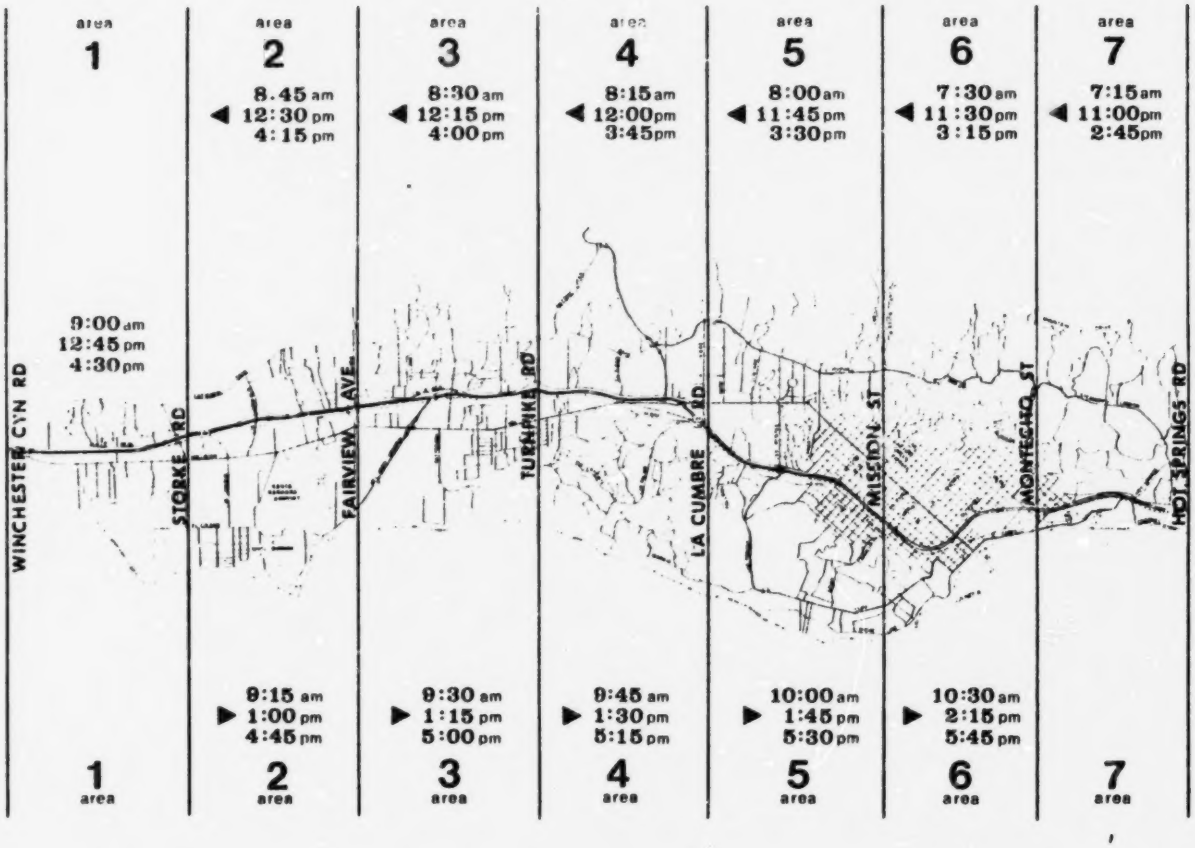


FIGURE 1-35. ROUTE AND SCHEDULE FOR SANTA BARBARA "HANDITRANS"

handicapped and non-handicapped students together on the same buses. The most common practice is to use medium to small-sized buses for the transportation of the handicapped. In rural districts these are used to transport non-handicapped students living on the same routes. Smaller buses are practical not only for the smaller numbers of children in special education (when transported separately) but also because some areas have limits on the length of time a child can spend on a bus. A large bus with many stops might exceed this limit if it had many handicapped pupils along its route.

Passengers in wheelchairs on school buses are treated differently from those in wheelchairs on public transit buses. In California, at least, the bus driver must assist the wheelchair pupil in boarding and, if a lift is used, must stand by while it is operating. Generally, the drivers also attach the wheelchairs to the securement devices.

1.4 SAFETY STANDARDS

Entrance (ramps and lifts) and safety devices used in the transportation of the handicapped must meet a variety of safety standards, including those applying to vehicles in general, to buses, to school buses, to transit buses, to buses which are used for the transportation of the handicapped, and to the operation of such devices. These standards may also be grouped according to their responsible agencies. For convenience we have divided them into NHTSA regulation, UMTA regulation, and state and local regulation.

1.4.1 NHTSA Regulations

According to FMVSS 208 (Reference 71), all bus drivers must either wear a Type 1 or Type 2 seatbelt, or have a passive restraint system. Additionally, for the school buses weighing less than 10,000 pounds, all seating positions must have a lap belt restraint system. FMVSS 222 (Reference 17) requires forward facing bench seats for all school bus passengers. The back surface of the seat must not be more than 21 inches forward of the seating reference points (see Figure 1-31 above) of the seat behind it.

The seat back must be 21 inches high from the seat cushion (in a front projected view), and the average width of the seat back must be at least 90 percent of the seat width. When test loads are applied, seat backs must deflect both forward and backward in accordance with the specified force-deflection curves, and the seat and all its components must remain attached. The seat cushion must stay in place when subjected to an upward load five times its weight. If a seat does not have another seat in front of it, a padded restraining barrier must be placed no more than 20 inches forward of the seating reference point. The barrier must have the same size, shape and characteristics as a seat back. All surfaces which could be contacted within the head-on knee-impact zones must be padded with energy absorbing materials. (There also are specific sets of criteria for the behavior of the seating materials under certain kinds of impact.)

For all motor vehicles, FMVSS 302 (Reference 72) specifies that all materials within 1/2 inch of the occupant compartment's air space must meet specific nonflammibility requirements. The exact test and flammability criteria are given in the standard.

FMVSS 301 (Reference 73) sets standards for gas tanks; in this standard, school buses over 10,000 pounds must be able to sustain a 30 mph moving contoured barrier crash (the barrier striking at any point or angle) without spilling more than a specified amount of fuel.

1.4.2 UMTA Regulations

UMTA Regulation 609.15 specifies that the UMTA will provide federal funding only if the bus design provides for a wheelchair accessibility option that includes both a lift or ramp and a securement device and location.

UMTA has also set up guidelines (Reference 75) which specify dimensions of seat locations and passageway clearances: the space between seats must be a minimum of 27 inches and must allow for the increased maneuvering room required for wheelchair footrests. They also specify durability tests and make a number of general recommendations – for instance, that lifts should not compromise normal

entry dimensions, and that wheelchair accomodations should be as close to the lift as practical and provide the clearances specified in the guidelines.

1.4.3 State and Local Regulations

In addition to the Federal standards, some states have established standards for transporting, loading and unloading physically handicapped and wheelchair-bound pupils. For instance, California Standard 4322 is quite comprehensive. At least three securement points are required for a wheelchair, and the securements must be strong enough to keep the chair in place in a rollover. The fastening devices must not protrude more than 1-1/2 inches from the floor. Each of these securement devices must be a belt bolted to the metal structure of the bus in two points, or a metal securing device also bolted to a structural member of the bus. The wheelchair may face any direction. Wheelchair passengers must be belted to the chair while being loaded, unloaded and transported. In buses carrying pupils in wheelchairs, at least one floor level emergency door is required. This door must be separate from the normally used door(s) and must provide an unobstructed opening of at least 24 inches. Aisles must be wide enough to allow passage of wheelchairs to the emergency and entrance doors. Special wheelchair or lift entrances should provide for easy manual release from inside or outside. The door should be at least 24 inches wide and have a head cushion on the top opening edge. Lift devices (and necessary structural changes) must be installed or approved by the bus manufacturer. The device should not be arranged in such a way that the driver must leave a pupil unattended on the loading device outside the compartment. Lift platforms must have a positive method of preventing an unbraked wheelchair from rolling off. Loading devices in the stowed position must be secure (no hazardous movement) and have padding on all exposed edges and protrusions. The surface of the loading device must have a non-skid covering material.

We contacted a number of other states about their regulations on the transportation of the handicapped. The salient points of these regulations are outlined in Table 1-24.

TABLE 1-24. SOME OF THE STATE REGULATIONS FOR TRANSPORTATION OF HANDICAPPED STUDENTS

State	Differences Due to Bus Types	Lifts and Ramps	Additional Requirements
Arizona/ Louisiana*	None mentioned	Specific construction requirements, lifting capacity, dimensions, safety consideration, operation by attendant	Emergency door, aisle and lighting specifications. Hand rails available. (Standards are 11 years old.)
Georgia**	Do not use vans. Conventional buses only.		
Minnesota***	None mentioned.	None mentioned.	No specific requirements for handicapped. Only general for handling and available types of transportation.
Missouri**			Only general standards for buses. Buses may be modified; standards are up to the school boards.
New Jersey**			In process of making standards. Present regulations specify handicapped must be transported. No details available now.

TABLE 1-24. (Cont'd)

State	Differences Due to Bus Types	Lifts and Ramps	Additional Requirements
New York	None mentioned.	Types and dimensions, specifics of operating and control types, lifting capacity. No rear lifts or ramps.	Locations of seats, barriers, emergency exits, types of securements.
North Carolina**			No standards, except that the handicapped must be transported. Details decided by parents and school districts.
Ohio	Belts allowed under 10,000 pounds.	Requirements for types of lifts/ramps, dimensions, control types and lifting capacity.	Requirements for aisle widths, wheelchair securements, barriers and lighting.
Pennsylvania	Exceptions for buses under 24 passengers	Ramp and lift requirements for lifting capacity, construction type dimensions, reinforcement of buses.	Specifications for stanchions, aisle widths, lighting and handrails. Standards being revised.
Texas	None mentioned.	Operating requirements; construction dimensions; specifications for protection, controls and lifting capacity.	Requirements for wheelchair securements, seat belts. Webbed cloth unacceptable for wheelchair locks.

*Both states have the same requirements.

**Information obtained through telephone conversations.

***Recently (late 1980) the state of Minnesota has included performance standards for wheelchair securement systems.

1.5 CONCLUSIONS

1.5.1 Standards and Regulations – Crash Protection

FMVSS 222 specifies crash protection standards for school bus occupants (Reference 17). Energy absorbing padding is required on seat backs, stanchions and modesty panels. Seats must be forward-facing with a specified maximum distance between them.

In addition to the Federal standards, some state governments impose regulations. In California (Reference 18), for example, the state standards describe equipment and procedures for transporting wheelchair seated passengers. The primary deficiency in the California regulations is in the performance requirements for the wheelchair securement devices. Requirements for operating the devices and for attaching them to the bus exist, but performance standards for the devices themselves are lacking. The adequacy of the present devices is not known.

Most of the regulations are generally accepted as necessary and useful, although some people question the practicality of the maximum of 20 inches allowed between seats. Many high school students are too large to fit into this space (in fact, the maximum distance was recently changed to 21 inches for this reason).

In FMVSS 208 (Reference 71), the only requirement is that the driver wear a seat belt. However, for buses weighing 10,000 pounds or less, all seating positions require seat belts.

1.5.2 Transportation Needs of the Handicapped

Approximately 5.0 percent of the U.S. population is transportation handicapped in some way. About 5 percent of these persons are confined to wheelchairs. Other handicap conditions include blindness and partial blindness, hearing problems, severe arthritis, temporary illness or injury, heart problems, etc.

Handicapped people tend to have less access to automobiles than the general public have lower employment rates because of this. Improved transportation for handicapped persons (both transit and school bus) will likely improve this situation by providing better access to work, education, shopping and recreation (Reference 54). It would allow these persons to be less isolated, as well as provide opportunities for them to enjoy a more varied lifestyle (Reference 54).

Problems associated with the present systems vary depending on the physical capabilities of the handicapped person using the system. Most communities have school buses or vans with lifts or ramps and restraints for wheelchair-confined and other handicapped people. Loading devices that seem relatively safe and efficient are available, although many school buses have only ramps or lifts that must be partially manually operated (and thus are physically demanding on bus drivers). Several types of wheelchair tiedowns are commercially available. These have been tested and evaluated for safety and performance capabilities. However, there is no accepted design and performance standard to evaluate them. According to research conducted at Wayne State University (Reference 57), no existing system provides adequate protection for handicapped passengers on buses. The Wayne State study also revealed that many wheelchair securement devices are slow and awkward to attach. For school buses, it is not necessary (and in some cases not a good idea) to permit the wheelchair occupant to operate the restraints. But, because handicapped children have such diverse needs, capabilities, and physical limitations, it is difficult to design a single crash protection system for handicapped school buses that satisfies every individual requirement. The best that is available today (which may be adequate in many cases) is padded seats and seat belts.

Needs for safety provisions on transit buses will likely differ from those required for school buses. Since one-third of the handicapped need door-to-door service, they could not use normal fixed route buses even if the buses are provided with special equipment (Reference 54). Some communities have special ride services for the elderly and handicapped, but many have no public transportation that can accommodate wheelchairs. For the ambulatory handicapped, lower floors and steps are needed. For wheelchair-seated riders, wide aisles, space allocation and safe securement systems are required. In contrast to school buses, the securing devices should be operable by the person

in the wheelchair. These devices must, therefore, be within easy reach and not require unusual strength for operation. A lift or ramp is necessary for loading and unloading. The type and placement depend on the intended use. Ramps should have no more than a 10 percent incline. On buses that provide special handicapped services, a lift and/or ramp either on the side or in the rear is sufficient because the driver/operator can provide assistance. For fixed route or mixed passengers (handicapped as well as non-handicapped riders), it is usually preferred that the lift/ramp be used with the standard door on the right front side of the bus. This door must, therefore, be wide enough for the easy passage of wheelchairs. In general, transit buses should be equipped to enable the handicapped to be more self-sufficient than would be required on school buses; in school transportation the driver is more likely to know each passenger's needs and to provide the required assistance. In a transit system (especially on a fixed-route bus) such personal attention usually is not possible.

1.5.3 Desired Characteristics of Equipment

Based on the information compiled, we have concluded that the desired characteristics of handicapped transportation equipment differ markedly for school buses and for transit buses. Further, transit buses should be separated into those on fixed-routes which have a mix of handicapped and non-handicapped passengers, and those that provide demand-responsive service, specifically for the handicapped. School bus equipment lifts and wheelchair tie-downs are operated with bus driver assistance in accordance with Federal and State regulations. Transit buses that transport only the handicapped should have wheelchair tie-downs that can be operated by a capable wheelchair-seated person, although driver assistance should be available, if needed. On a fixed-route integrated transit system the boarding, maneuvering and tying down of wheelchairs would have to be independent and efficient because of the operational requirements. The following compiles the desired characteristics of the equipment used for the transportation of the handicapped. These characteristics are derived from recommendations and comments from collected data during the state of the art survey.

- Conventional bus floors provide adequate strength for the securement of interior fixtures and required safety hardware. Currently the nominal step height is 12 inches. If this height were reduced to 8 inches, indications are that ambulatory persons with a handicap would have significantly less difficulty mounting the steps. Steps should not have protruding edges which could cause tripping. An integral step/lift fixture would appear to resolve most loading difficulties.

- Conventional transit buses have a single entrance for the regulation of fares. For a fixed-route transit operation the wheelchair loading device should be at the forward door in order to pass the fare box. School buses and special buses for the handicapped generally require an extra door with a lift or ramp on either the side or the rear. Each of these locations has positive and negative points. A lift door on the rear often requires the wheelchair passenger to go out into the street; on the other hand, its location inside the bus is less dangerous because the device is behind all the seating positions. Also, the fact that the bus has just driven over the loading area insures that the area is clear. Side doors may be preferred because they can open onto sidewalks and driveways, although the stowed equipment inside the bus could be a hazard in a collision. A curb or uneven surface could also cause difficulties if the bus cannot be aligned correctly with respect to it.

- Door widths of 29 to 38 inches are recommended for wheelchair access. Within this range the doors should be as wide as allowed by the bus structure and other space considerations.

- The seating positions specified in FMVSS 222 (Reference 17) can be satisfactory from a safety point of view for transporting the ambulatory handicapped in forward-facing seats. But, some side-facing seats may be required for handicapped persons who would have difficulty getting into and out of conventional forward-facing seats. Additional protection (in the form of belt restraints for side-facing passengers) is desirable. The seating in transit buses is satisfactory for the ambulatory handicapped, since the first two side facing seats are easily accessible and are designated for elderly and ambulatory handicapped passengers.

- Aisles in standard buses (both school and transit) are too narrow to accommodate wheelchairs. Aisles in buses that will carry wheelchairs must be widened to at least 29 inches to permit entrace, exit and easy accessibility to emergency doors.

- A cleared space of at least 25 by 41 inches, plus maneuvering space, is necessary for each wheelchair (Reference 60). To provide this space in most buses, seats would have to be removed or foldaway seats installed.

- The barriers as per FMVSS 222 are specified to provide adequate crash protection for forward-facing passengers in school buses. Additional padding or barriers may be needed in front of the wheelchair seating sections or side-facing seats provided for the handicapped.

- Emergency exits are already required on all buses, but on buses carrying wheelchair passengers the exits should be at floor level and should be of sufficient dimensions to allow easy passage by a wheelchair.

- Securements should be installed for each wheelchair. Although exact performance requirements for securement devices are not yet known, the devices should be capable of holding an occupied wheelchair in position during front, side, rear, and rollover crashes. They, therefore, should be secured to a sturdy structural part of the bus. Their operations must vary according to purpose. Securements for transit buses must be capable of being engaged and disengaged without requiring an unusual amount of strength. In school buses the levers and switches of wheelchair securements need not be operable by the wheelchair occupant. Also, securements should be designed on the basis of the strong points of wheelchair structures.

- Wheelchair loading devices must be provided, since standard bus entries cannot accommodate wheelchairs. Ramp inclines must not be steep (1 foot of rise needs 10 feet of run), when unassisted use is intended. Unless a strong attendant (driver or other person) is available to push, ramps would be impractical. In most cases, a powered lift would be necessary. The following lift features are preferable:

- A pressure sensing mechanism on the bottom of the platform so that the lift will stop upon contact with any surface or obstacle
- A safety flap on the bottom of the platform to prevent wheelchairs from rolling off during lifting
- A loose flap or other measure to prevent toes from being squeezed or jammed between the lift platform and the bus floor
- A capacity of at least 400 pounds
- A manual backup system, should the power system fail
- Operating controls at three locations: the driver seat, within reach of the person on the lift, and beside the lift (for a driver/attendant outside the bus). In a fixed-route transit bus, the lift/ramp should be located in the standard front doorway.

• Seatbelts are not practical for most seated passengers in fixed-route transit buses. Seatbelts should be provided for ambulatory handicapped passengers on school buses, and on demand-responsive bus services for the handicapped and/or elderly. Most school buses and buses for the handicapped are presently equipped with such belt systems. Supportive and/or padded restraints should be available for pupils unable to support themselves upright while the bus is in motion.

• Padding is presently required on school buses; FMVSS 222 specifies material characteristics and padding locations. Recent research by ASL Engineering, Inc. includes consideration of toxicity, flammability, energy absorption, and load distributing properties on all types of buses. The remaining portion of this program will consider material properties like toxicity and flammability, in addition to energy absorption and load distribution in material selection.

• Side-facing bench seats are more common in transit buses than they are in school buses. In transit buses the side-facing seats are found on both sides near the forward entrance. In the rear of the bus they are usually placed over the wheelwells. FMVSS 222 has made side-facing seats illegal on all school buses except for those that transport handicapped school children. Usually the small school buses and vans have such seats. These are generally placed in the rear portion of the bus, near the emergency exit. Seatbelts or other containment features must be provided with side-facing seats intended for use by the handicapped.

SECTION 2
ACCIDENT, INJURY AND FATALITY DATA ANALYSIS

2.1 INTRODUCTION

In Task 3 we conducted a detailed investigation of the available information on bus accidents and their related injuries. Our objectives were to identify

- Injury causing mechanisms in the interaction of passengers and bus interiors during accidents
- Causes of injuries to bus passengers during both normal bus operation and accidents
- Specific factors (such as passenger size, location, seating location, etc.) that have a strong influence on the likelihood of injury in an accident
- Crash characteristics (such as manner of collision, initial impact point, type of accident, etc.) that are associated with severe injuries and fatalities.

Figure 2-1 shows the methodology used in our injury and fatality data analysis and a number of the data sources which were approached for information. We analyzed the collected data according to the four objectives of Task 3. The results of the analysis are documented in this section. We further analyzed these results for their usefulness in developing crash protection systems for handicapped bus passengers. This study produced a series of design guidelines, which are listed in Subsection 2.5.

At the beginning of this effort we anticipated that there would be limitations in the data available on the involvement of handicapped people in bus accidents. But we hoped that the collection of in-depth information about conventional bus service accidents, injury severities and causes, and operational modes and users would allow a reasonable extension and projection of the available data base to the environment of a hypothetical handicapped passenger in a bus.

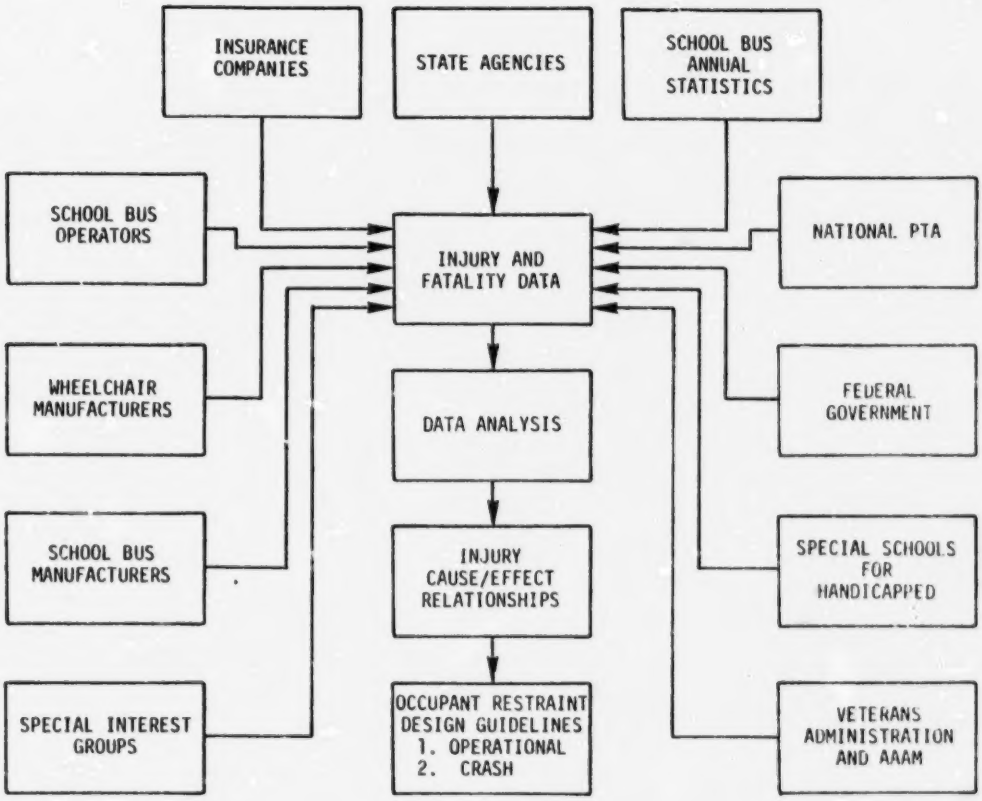


FIGURE 2-1. METHODOLOGY FOR INJURY AND FATALITY DATA ANALYSIS

It should be understood that this investigation was not intended to parall 1 the efforts of others. The majority of previous accident reports have been concerned primarily with establishing fault or blame in the accident. But they have paid little attention to injury causes.

The most comprehensive analysis prior to this study was presented in a DOT report (Reference 70) to Congress in January of 1977. That report had much the same intent as the present Task 3 study, and both efforts met many of the same obstacles in data collection and analysis. To quote the report,

> In order to place the problems examined in the MDAI and other intensive studies in a perspective permitting broad operational remedy, knowledge concerning the prevalence or magnitude of accident-injury

types and their causes must be obtained. This can be done either by taking a census or conducting surveys of the crash events. At the present time, no mechanism exists to obtain either the mass data or the sample statistics which are nationally representative.

Typically, accident reports present the data in distinct categories. By the time they are included in the accident report, the raw data have been analyzed and segregated with a particular purpose or presentation in mind. This often means that the ability to cross-correlate or re-analyze the data has been unintentionally nullified. For example, the Bureau of Motor Carrier Safety (BMCS) of the U.S. Department of Transportation (DOT) annually publishes "Accidents of Motor Carriers of Passengers" (References 76-79). This book presents the data in five categories:

- Highway Environment
- Time and Place
- The Driver
- The Vehicle
- The Accident Itself.

Unfortunately, only one category ("The Accident Itself") carries data of use to the Task 3 study, and these data are insufficient for our purposes. Figure 2-2 shows the percent distribution of fatalities by vehicle movement (in bus-related accidents). These statistics represent a total of 62 fatalities.

The relevance of these percentages is deceptive. The data base includes both bus/stationary object and bus/other vehicle accidents. Further, each vehicle and each collision is treated separately; if two cars collided head-on and one proceeded into the side of a bus which was making a left turn, the report would include three entries in the "proceeding straight" category, two in the "head-on" category, and one in the "left turn" category. Further, this sort of information affords no indication of probable impact point or collision mode frequency.

We have organized the data useful to the Task 3 accident and injury analysis into two categories: "Accident Mode Data" and "Injury Causation Data." Where applicable, the effect of the present Federal Motor Vehicle Safety Standards on injury causation has been taken into account, and those injury mechanisms modified and commented on accordingly.

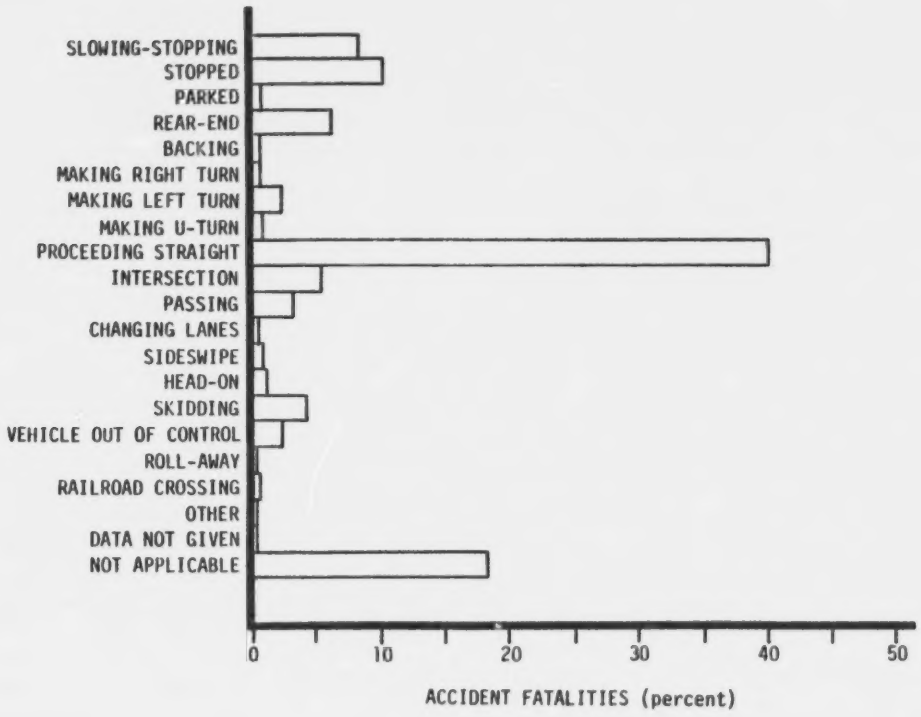


FIGURE 2-2. ACCIDENT FATALITIES FOR VEHICLE MOVEMENT - 1975

2.2 DATA SOURCES

2.2.1 Available Sources

We contacted a large number of agencies and organizations for accident reports, statistical data and past or ongoing bus safety research. Appendix C presents a complete list of these contacts. The reports and publications that we surveyed dealt with two major concerns: factors in bus accidents and safety, and injury data and statistics. These works are listed in the bibliography at the end of the report.

2.2.2 Type of Data Available

We found that there were three types of useful information: reports on specific accident cases, annual statistics and the findings of prior research efforts. Only 62 of the collected accident reports had sufficient detail for use in this study. These reports were analyzed and the data grouped by accident type, speed and injury severity to provide an overall picture of the accident environment. It should be noted that the most detailed of these reports were made in response to the more severe accident cases. Generally, the fatal accidents tend to attract the most attention and are investigated in better detail.

Annual statistics given out by various organizations were the second information source. These statistics concerned the bus types, bus usage, trip characteristics, occupant profiles, accident/collision types and frequencies, and injury severity profiles.

The third source was provided by prior research studies (References 80-82). We investigated the conclusions and recommendations of these programs and used them when they were verified and found to be relevant.

2.3 FINDINGS OF DATA SEARCH

2.3.1 Statistical Information

Examples of typical statistics collected are presented in the following subsection. Tables 2-1 and 2-2 are collections of data contained in four successive yearly files of the Department of Transportation's Fatal Accident Reporting System (FARS; Reference 83).

Selected data from the 62 detailed reports provide enough accident mode data for an additional profile of accident types. Table 2-3 is a summary of these data. There are more than 62 entries in Table 2-3 because of rollovers subsequent to initial impact.

TABLE 2-1. INITIAL IMPACT POINT OF FATAL BUS ACCIDENTS – 1975, 1976 AND 1977

Initial Impact Point	Total	School Bus	Transit Bus	Other Bus	Unknown Bus	Unaccounted For
Total	950	371	380	45	66	88
Non-collision	52	14	26	3	3	6
1 o'clock	63	13	27	6	7	10
2 o'clock	23	10	10	0	1	2
3 o'clock	50	17	26	3	3	1
4 o'clock	14	6	6	1	1	0
5 o'clock	23	5	15	1	1	1
6 o'clock	61	28	21	3	4	5
7 o'clock	20	11	6	0	2	1
8 o'clock	14	7	5	0	2	0
9 o'clock	32	18	12	0	2	0
10 o'clock	11	8	1	0	1	1
11 o'clock	80	28	24	6	9	13
12 o'clock	408	139	156	20	26	47
Top	1	0	0	1	0	0
Undercarriage	68	35	31	1	0	0
Unknown	30	12	14	0	4	0

TABLE 2-2. MANNER OF COLLISION OF FATAL BUS ACCIDENTS – 1975, 1976 AND 1977

Manner of Collision	Total	Percentage	School Bus	Transit Bus	Other Bus	Unknown Bus	Unaccounted For
Total	945	100	370	377	45	66	87
Not applicable	457	48	157	226	18	27	29
Rear end	87	9	35	28	4	8	12
Head-on	153	16	70	35	11	14	23
Angle	223	24	102	78	10	14	19
Sideswipe	21	7	5	8	1	3	4
Unknown	1	< 1	0	1	0	0	0
Rear-to-rear	3	< 1	1	1	1	1	1

TABLE 2-3. FREQUENCY OF ACCIDENT MODE, FROM 62 ACCIDENT INVESTIGATIONS (53 SCHOOL BUS, 9 INTERCITY BUS)

	Rollover	Right Side	Left Side	Rear	Frontal (Oblique and Straight-on)
Incidence	26	9	4	10	19
Percent of Total	38	13	6	15	28

In reviewing bus accident data in intra-city activity, it is often the case that many of the injuries are not suffered by the bus occupants. The California State Department of Highway Patrol publishes the "Annual School Bus Accident Reports" (References 84-86). Table 2-4 summarizes their data for a nine year span. Figure 2-3 shows a typical presentation of the extent of injury.

Some of the significant results from data presented in Tables 2-1 through 2-4 and in Figure 2-2 are:

- Twelve o'clock appears to be the dominant impact point for fatal accidents.
- When the 11, 12 and 1 o'clock (fatal collision) impact points are combined, they account for the majority of the fatal accidents.
- Rollover as a result of non-collision single vehicle accident and rollover subsequent to primary impact are also very common in bus accidents.
- School bus related fatalities include a large percentage of victims who are either pedestrians or occupants of other vehicles.

2.3.2 Injury and Seating Locations

Figures 2-4 through 2-7 depict the seating plans and the resulting injuries to the occupants of buses involved in nine of the accidents described in the 62 accident reports mentioned above. The occupants who did not have significant injuries are shown by a broken triangle, those who had serious injuries are shown by a complete triangle and those with fatal injuries by a filled in triangle.

The results of the accident data analysis show the following tendencies:

- The driver's station appears to be a vulnerable position, particularly in frontal impacts.
- The serious injuries and fatalities are predominantly in the immediate vicinity of the primary impact zone. This applies for front, side and rear collisions.

TABLE 2-4. SCHOOL BUS ACCIDENT VICTIM TYPE DURING FISCAL YEARS 1967/1968 TO 1975/1976 (STATE OF CALIFORNIA)

Victims by Type	1967/68		1968/69		1969/70		1970/71		1971/72		1972/73		1973/74		1974/75		1975/76	
	No.	% of Total	No.	% of Total	No.	% of Total	No.	% of Total	No.	% of Total	No.	% of Total	No.	% of Total	No.	% of Total	No.	% of Total
Pupil passenger																		
Killed	-	-	-	-	-	-	-	-	1	10	-	-	-	-	1	33	-	-
Injured	303	46	259	41	213	36	189	332	253	41	167	31	222	42	309	52	292	54
Pupil pedestrian																		
Killed	1	9	2	22	-	-	2	17	-	-	1	13	1	14	1	33	1	33
Injured	25	4	21	3	36	6	37	7	40	7	52	10	24	5	27	5	24	4
Other than pupil school bus passenger																		
Killed	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Injured	3	1	3	1	15	3	19	3	47	8	48	9	69	13	59	10	29	5
School bus driver																		
Killed	-	-	1	11	1	10	-	-	-	-	-	-	-	-	-	-	-	-
Injured	44	7	43	7	41	7	44	8	36	6	39	7	25	5	28	5	35	7
Other vehicle occupant or pedestrian																		
Killed	10	91	6	67	9	90	10	83	9	90	7	88	6	86	1	33	2	67
Injured	286	43	302	48	289	49	280	49	237	38	242	44	188	36	174	29	160	30
State Total																		
Killed	11	100	9	100	10	100	12	100	10	100	8	100	7	100	3	100	3	100
Injured	661	100	628	100	594	100	100	100	613	100	543	100	528	100	597	100	540	100

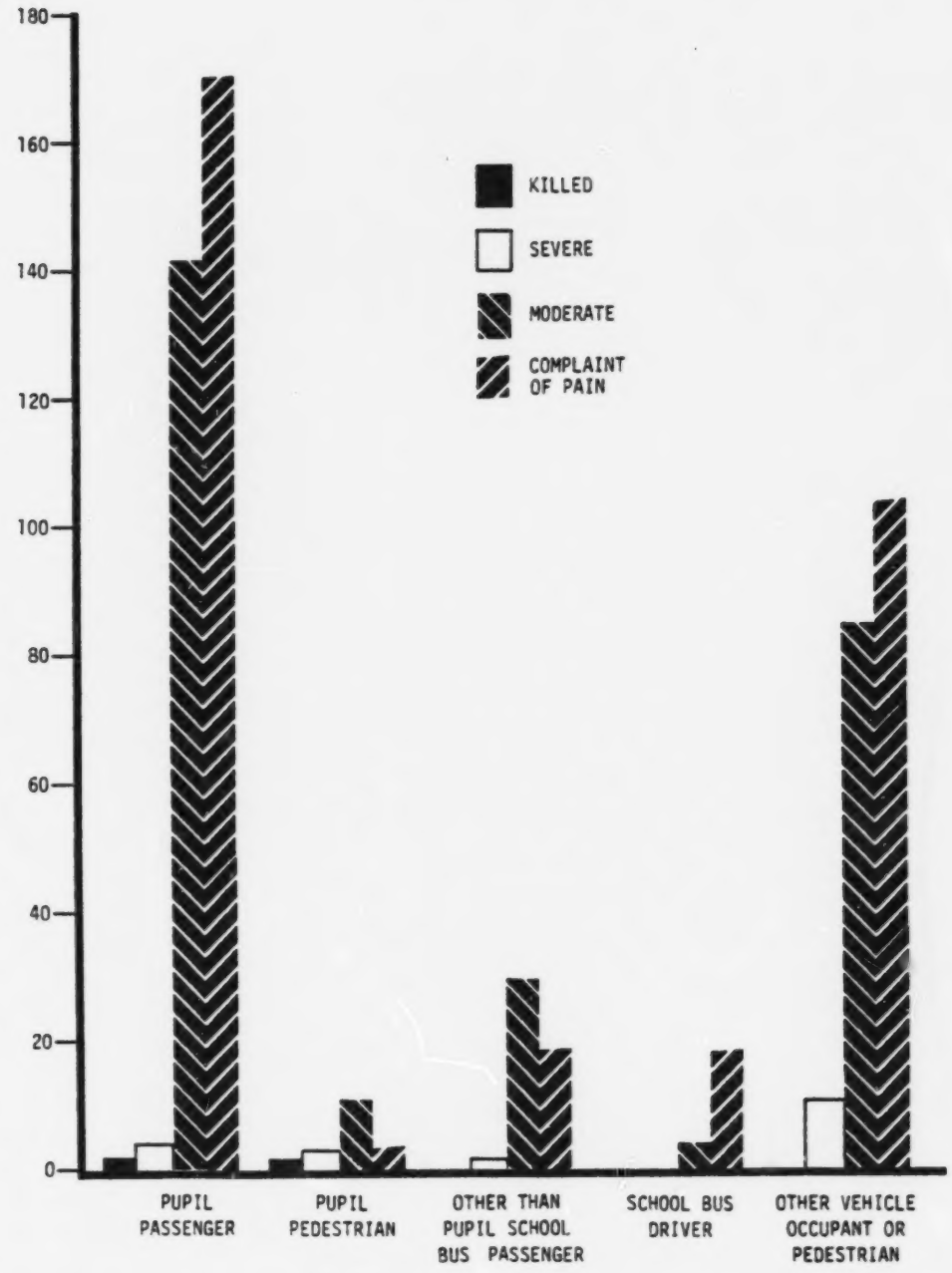
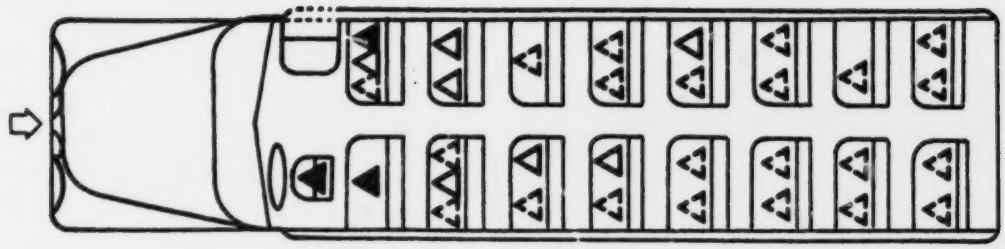
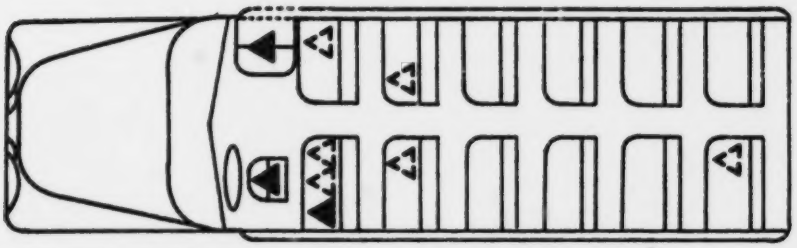
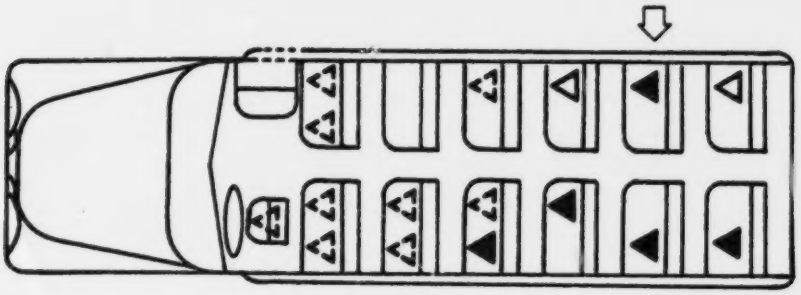


FIGURE 2-3. SCHOOL BUS ACCIDENT VICTIMS BY EXTENT OF INJURY DURING FISCAL YEAR 1976/1977
(STATE OF CALIFORNIA)





16 out of 17 occupants ejected, 9 killed; ⇧
seating positions of some not known



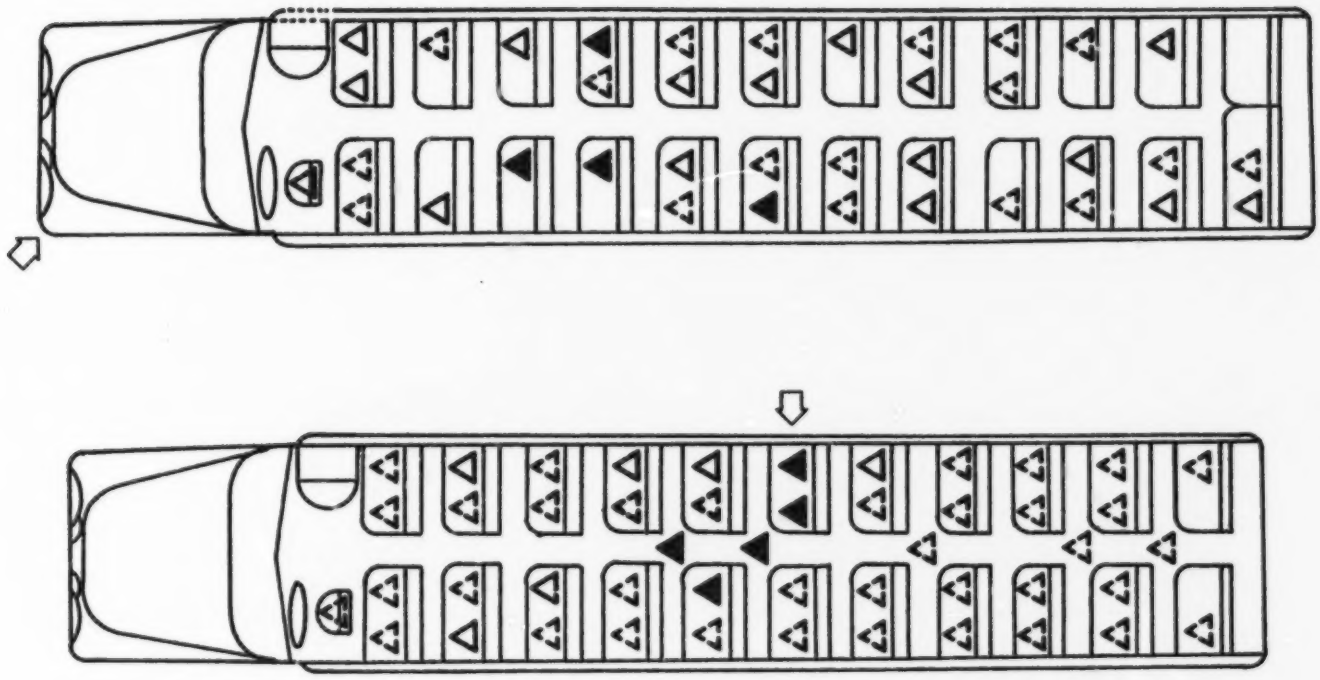
△ = Bus Occupant

△ = Occupant Seriously Injured (AIS 4 or 5)

▲ = Occupant Killed

⇨ = Main Impact Point

FIGURE 2-4. COLLISION MODE AND INJURY/FATALITY PATTERNS BY SEATING POSITION



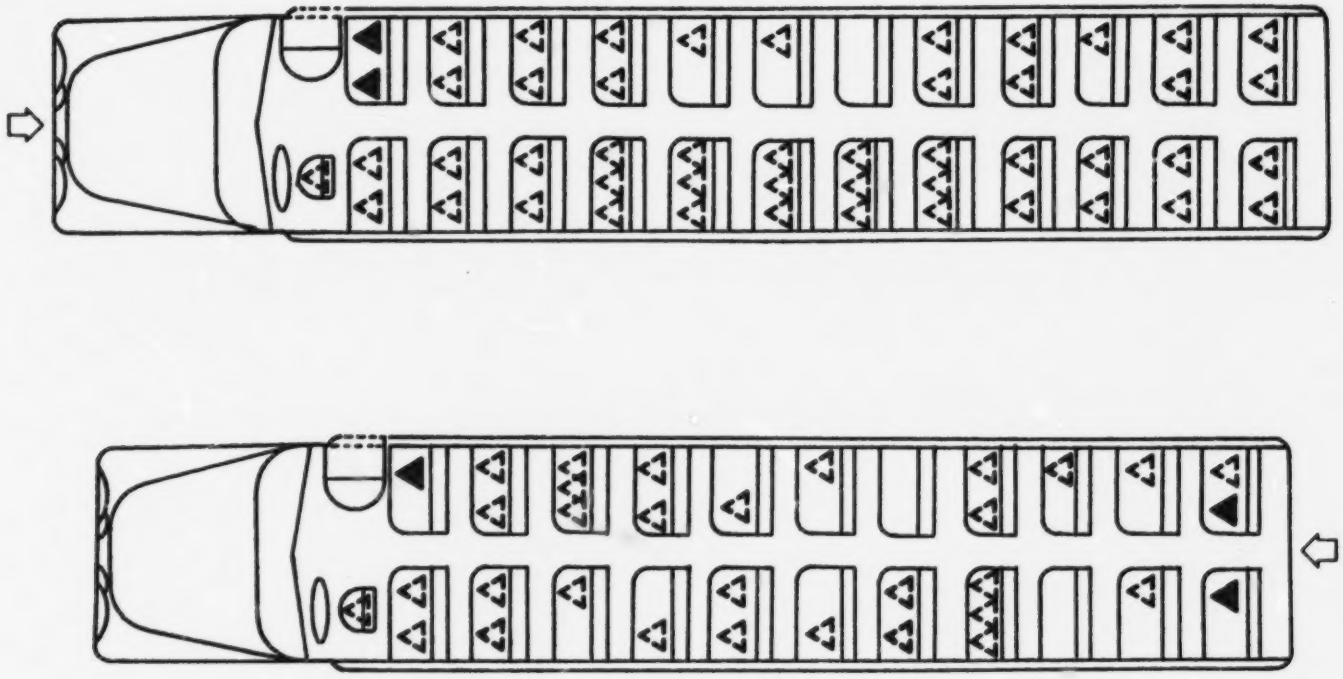
△ = Bus Occupant

△ = Occupant Seriously Injured (AIS 4 or 5)

▲ = Occupant Killed

⇨ = Main Impact Point

FIGURE 2-5. COLLISION MODE AND INJURY/FATALITY PATTERNS BY SEATING POSITION



△ = Bus Occupant

△ = Occupant Seriously Injured (AIS 4 or 5)

▲ = Occupant Killed

⇨ = Main Impact Point

FIGURE 2-6. COLLISION MODE AND INJURY/FATALITY PATTERNS BY SEATING POSITION

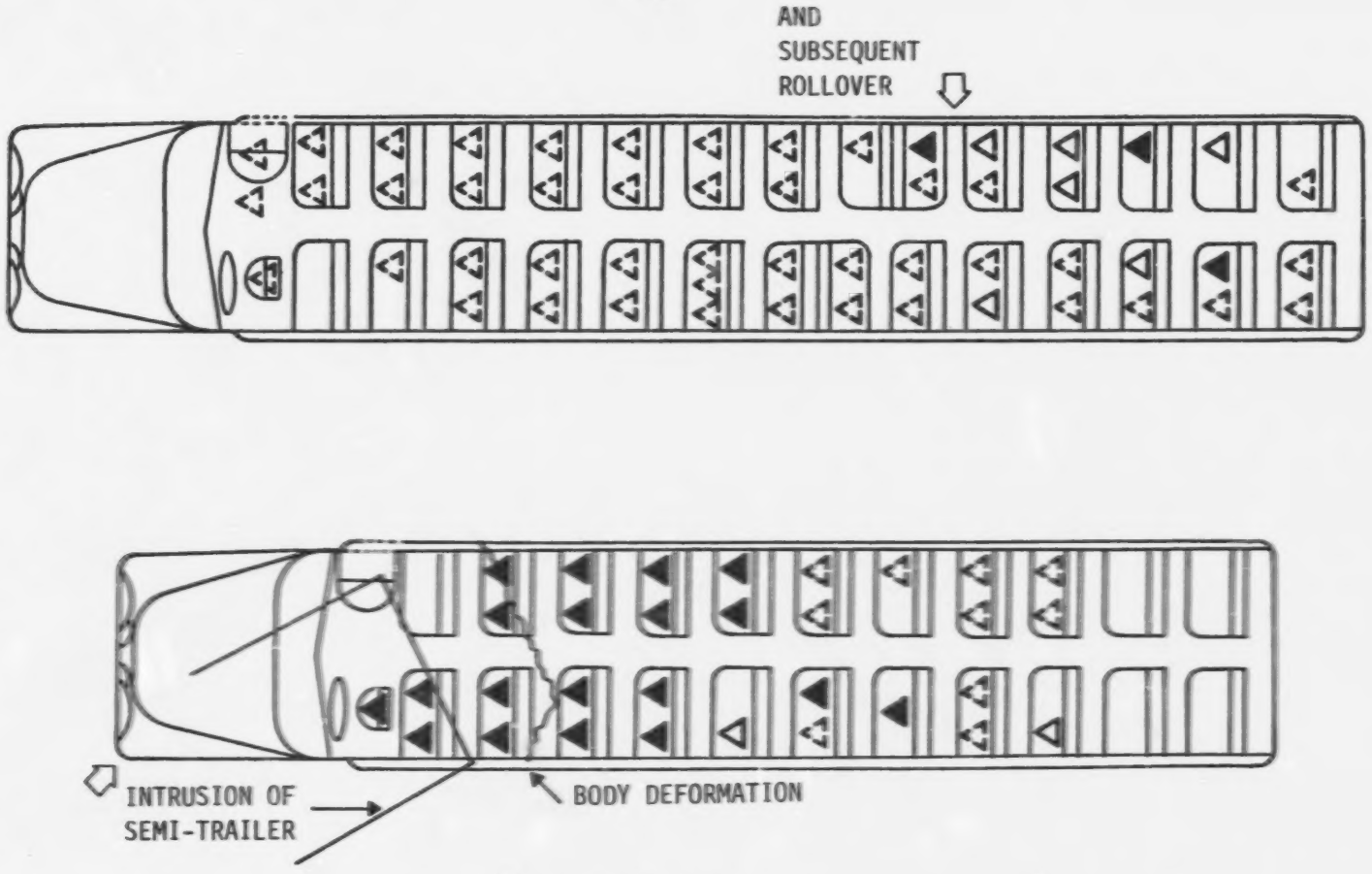


FIGURE 2-7. COLLISION MODE AND INJURY/FATALITY PATTERNS BY SEATING POSITION

2.3.3 Comments and Conclusions from Other Studies

Our survey of the earlier studies showed clearly that:

- Most reported injuries occur to the head and face in frontal collisions and to the face and knees in rear collisions. Seats, especially seat backs (of the seat in front of the passenger), cause 70 to 90 percent of the injuries.
- Shoulder and head injuries predominate in side collisions.
- In rollover accidents, shoulder, head and facial injuries are dominant (in the order listed). Seats are the primary source of injury in this sample.
- Ejected occupants are significantly more likely to be seriously or fatally injured than are non-ejected occupants.

Some additional comments (and their sources) collected during our survey are listed below:

- Regarding a bus front to van rear, bus rollover accident, Dynamic Science, Inc. states in their Report NI-4-32 (Reference 87), "Injuries to occupants were caused by contact with window glass, side and roof structures, other occupants, and loose seat cushions."
- Reporting on an accident in which a bus struck a car and then rolled over, the University of Michigan states in their Report AA-316 (Reference 88) that the "unforgiving interior of V-1 [bus] (metal seat frames, unpadded seat backs, and tempered side glass) increased injury." [pre-FMVSS 222]
- The University of New Mexico comments in their Report 102 (Reference 89) on an accident in which the front of a bus hit a rock and then a tree: "Injury Causation: Most of the seats broke loose from the bus floor. The resulting exposed hardware caused minor to moderate injuries to most of the occupants."
- According to Southwest Research Institute Report 7519 (Reference 90), in an accident in which a truck struck the front left of a stopped bus, "The interior of the school bus did not offer adequate protection to the occupants. Sharp exposed sheet metal in the occupant compartment was noted as a potential injury hazard."

2.4 COLLISION MODES

2.4.1 Accident Frequency by Mode

Rollovers seem to be prevalent in serious bus accidents – as a result of both the primary impact and the loss of control of the bus. Of the accident cases examined, 42 percent involved rollovers; the FARS (Reference 83) data show 48 percent of the severe accidents as "non-collisions" – which can be assumed to be mostly rollovers. Bus rollovers tend to cause serious damage and casualties. Rear-end impacts account for a relatively small portion of the accidents, according to Tables 2-2 and 2-3 above (which include only fatal accidents). BMCS (Reference 76) lists 10 and 14 percent rear-end impacts (for 1973 and 1974, respectively), but these are limited to accidents causing at least $2,000 damage. We suspect that rear impacts of buses are more frequent than reported, but are less likely to cause excessive damage and injury – therefore rating low in the "serious" accident data. School buses are often impacted from the rear, due to their frequent and sometimes unexpected stops. Other observations of accident mode trends are that right side impacts are common in out-of-control accidents involving fixed objects (such as guardrails, trees and embankments) and that left side impacts are more common in collisions with other vehicles.

2.4.2 Accident Characteristics: Transit Buses versus School Buses

Accidents involving transit buses and school buses differ somewhat due to the dissimilar characteristics of their routes and usage. Injuries on transit buses are often due to falls and bumps on the bus during deceleration – mostly involving non-seated passengers. Of the bus accident reports encountered in this survey (all considered serious accidents), none of the buses were city transit buses; transit buses generally run on low-speed city streets and are less prone to severe impacts. Statistics from the Bureau of Motor Carrier Safety (Reference 76) show that there are few injuries and deaths in business district bus accidents, compared with the number in residential and especially rural areas (Table 2-5).

TABLE 2-5. TRANSIT BUS ACCIDENT LOCALE

Year	Accident Site	Number of Accidents	Number Killed	Number Killed per Accident	Number Injured	Number Injured per Accident
1973	Rural	301	22	0.073	635	2.1
	Residential	126	4	0.032	136	1.1
	Business districts	188	0	0	233	1.2
1974	Rural	303	13	0.043	779	2.6
	Residential	96	3	0.031	111	1.2
	Business districts	274	2	0.007	322	1.2

School bus-related injuries, on the other hand, are rarely caused by falls during normal use – as seats must be provided for all passengers. School bus travel accidents are less likely to be in-city; rural and residential road accidents are predominant on regular routes, as well as on highways during field trips. Nearly half (44 percent) of the NTSB reported school bus accidents occur during field trips or other long distance travel.

2.4.3 Severity and Causes of Injury

In bus rollover accidents, irrespective of whether the rollover occurs in the primary or secondary accident phase, a large percentage of severe and fatal injuries result from structural failure and passenger ejection. Rollovers also overextend the containment capabilities of the seats, subjecting the passengers to repeated contact with aggressive features of the coach interior. Passengers retained in the coach during rollover typically experience major head and chest injuries caused by impacts with stanchions, seat backs, anchorages, other passengers and exposed body panel edges. Ejected passengers suffer major

injuries either from elements of the accident site terrain or re-involvement with the still-moving bus. During ejection the passenger may incur severe injuries from shattered windows or ragged edges of body panel ruptures.

Intrusion of the passenger compartment (gross structural deformation of the coach at the impact point) produces severe injuries to occupants of the intrusion zone. Intrusion introduces foreign and aggressive elements to the passenger environment, unrelated to the bus interior. Passengers near, but not occupying, the intrusion zone experience high accelerations and secondary impacts with elements of the bus interior (due to the general involvement of large masses at high speed). Commonly, intrusion zone occupants suffer major body injuries.

Frontal impacts generally produce severe injuries of the head, neck and face. These types of injuries occur upon impact with seat backs, stanchions and hand rails. The introduction of FMVSS 222 addressed these problems and since the FMVSS 222 compliance seats were introduced in school buses, the severity of these types of injuries might have decreased. Leg injuries may result from contact with seat backs and supports. Standing occupants in intra-city transit buses experience higher levels of injury than seated occupants, due to lack of containment and greater exposure to aggressive elements of the bus interior. Standees are typically thrown to the floor and may encounter seat supports and anchorages. Intra-city transit buses, in addition to having a higher incidence of standees, also present greater hazard in the large number of stanchions and seat back handrails. Without adequate containment, many high acceleration frontal impacts result in the ejection of the forward seated passengers and standees through the windshield.

Low to moderate speed rear impacts of buses cause little injury to seated passengers. Transit bus standees experience effects similar to comparable frontal impacts. High acceleration impacts, with adequate passenger containment, often produce only low level injuries. High speed impacts with intrusion often affect only those occupants in the immediate vicinity.

Sidewise acceleration of passengers (due to perpendicular side, frontal oblique and sideswipe impacts) affects far-side occupants to a greater degree than near-side occupants. The lack of lateral seat containment allows contact with seat

structures and other occupants. Near-side occupants suffer their greatest injuries from contact with window assemblies and glass.

2.5 SUMMARY OF SCHOOL BUS SURVEY RESULTS

The National School Transportation Association (NSTA) conducted a "mini-survey" of its members to find out about their school bus transportation practices and accident/injury experience. A total of 23 school bus transportation organizations responded to the questionnaire (Appendix C). The results of the survey are summarized in this section. It is appropriate to mention that the results summarized here are not intended to provide any statistical information. The results presented, however, are very instructive.

The sample collected is not large enough to provide representative (regional or national) information. In fact, no effort was made to create such a correlation. The information contained in the responses provides, nevertheless, some insight into actual transportation practices and accident/injury experience.

A number of the replies to the survey did not respond to all of the categories; consequently, in many cases the sum of the columns and rows do not equal 23, and at times equal more than 23 because of multiple response. In addition, several respondants elaborated on their responses; these are directly quoted as possible useful information.

Survey Coverage

Number of respondents	23
Location:	
Primarily rural	5
Urban	3
Suburban	5
Urban & suburban	4
Urban, suburban & rural	5

Accident and Injury Data

- Number of accidents per 100,000 miles:

	1975	1976	1977
Rollovers	1	0	0
Rear impacts	12	21	11
Side impacts	9	14	15
Frontal impacts	8	16	7
	30	51	33

- Comments – correlations between the above accident modes and resulting injuries to passenger:

  "No injuries to passengers occurred due to the nature and location of accidents, at low speed. Fifty percent of such accidents have occurred when there are no passengers on board."

  "Frontal impacts resulted in more severe injuries and a larger number of injuries."

  "In frontal impacts injuries were caused by hitting seat backs."

  "Frontal impact caused a broken jaw and leg."

  "I would say that most of the injuries come from side impacts. This is probably due to greater frequency especially in intersections."

  "Two head injuries in rear impact."

- Comments – interior damage and deformation in specific cases:

  "Extensive damage to the right rear corner roof panels when a bus skidded into a telephone pole. They became dislocated and could have caused injury."

"Negligible damages - mostly corner deformation - one instance of floor distortion from side impact."

"We have had no interior damage. This is obviously due to the fine construction required for all school buses."

- Comments - correlations between seat positions and injuries:

"In Class II type van buses the first seat behind the driver seems more vulnerable."

Otherwise no comments, mostly no information about the seating positions of these injured.

- Major causes of injury in bus crashes:

Impact with seat back	8
Impact with other objects (side of bus, heads, windows)	5
Whiplash from rear impacts	1

- Weather, speed, or other vehicle actions critical to accidents:

Weather	10
Driver error	3
Other vehicle action	6

Comments:

"It is interesting to note that our experience has been that we have more accidents due to rain than winter conditions."

"Failing to adjust the vehicle speed downward during adverse weather conditions contributed to accidents."

- Details of any specific cases of accidents and/or injury on a bus transporting physically handicapped pupils:

  Only one detailed answer about an accident involving a car out of control striking the bus. The driver sustained chest injuries and 13 passengers were injured, as follows: 2 arm fractures, 11 facial cuts and bruises from flying glass and striking the seat back. All passengers and the driver were seat belted and in their seat after the accident.

Operational Profile of Buses Equipped to Transport Handicapped Pupils

- Type of wheelchair loading if wheelchairs are carried:

	Side	Rear	Not Specified
Hydraulic Lift	8	1	3
Winch Lift	1	1	0
Ramp Lift	2	1	4
Electric Lift	4	0	1

- Type and size of bus used:

15 passenger maxi-vans	5
Class II (up to 16 passengers)	2
Minibus (16 passengers)	3
Van (10 passengers)	7
Medium size (36 passengers)	1
Carry-all bus	2
Medium size (30 passengers)	5
Medium size (48 passengers)	7
Conventional size (66 passengers)	6

- Wheelchairs:

Where do they ride?

Front	15
Middle	12
Rear	8

Which way do they face?

Aisle	12
Front	7
Rear	0

How are they tied down?

Straps	6
Straps & Brackets	3
Brackets	2
Chair pin	1
Chains	1
Wheellocks	1

Does this method seem adequate?

Yes	14
Need improvement	4

Do passengers in seats wear seat belts?

Yes	15
No	8

Which way do the seats face?

Front	17
Side	0
Both	5

2.6 CONCLUSIONS

1. The accident data collected did not include a single case in which a wheelchair seated passenger suffered a serious or fatal injury.

2. Frontal impacts (11, 12 and 1 o'clock) account for the majority of the fatal and serious bus accidents.

3. Single vehicle rollover and rollover after the initial impact are involved in a large percentage of the fatal bus accidents.

4. Seat backs, stanchions, windows and structural deformation resulting from the accident appear to be the primary elements of the bus that cause injuries to the bus occupants.

5. The driver's station is very susceptible to serious and fatal injury, particularly during frontal impacts.

6. The injuries and fatalities produced by an impact are usually concentrated in the immediate vicinity of the impact.

7. No accurate data were available on the speeds of the buses at the times of impact or on the relative velocities of impact (when two vehicles were involved in the accident).

8. In general, it appears that the selected test speeds for the bus crash tests are those most likely to produce severe injuries for bus occupants. (This is discussed in Section 3 of this report.)

2.7 DESIGN GUIDELINES

Based on the state of the art survey and the accident, injury and fatality data analysis, we have identified the following as potential design requirements for the crash protection system development effort. This was not a contract task and data presented here should be treated as a general set of guidelines.

Wheelchair Sizes and Types

The crash protection systems will be designed around the standard Everest and Jennings manual wheelchair model T8A (250/260; Reference 2). This wheelchair was chosen because it is representative of 85 percent of the wheelchairs in use. However, even though we are designing systems primarily for the "standard" wheelchair, the designs will accommodate powered wheelchairs as much as possible. The dimensions of the Everest and Jennings model T8A (250/260) are

Overall length with footrests extended	44 inches
Overall width with footrests lowered	26-1/4 inches
Overall height	38-3/4 inches

Bus Dimensions and Interiors

There are four types of buses primarily being considered in this effort. They are the van type conversion, the busette and the conventional and unitized bodies. The transit buses are generally of unitized construction, but school buses are made in all four configurations.

The large school buses are 96 inches wide outside and 90 inches wide inside, with two 39 inch seats and a 12 inch aisle. The large transit buses are limited to 102 inches outside and 96 inches inside. There is no standard seating arrangement in transit buses, while there is more flexibility in arranging the wheelchair locations. These arrangements are, however, constrained by wheelchair location considerations such as how and where to pay fare and minimize schedule delays.

The small buses obviously have less interior width. The Thomas "Mighty Mite" is 79 inches wide inside, and its interior lengths range from 131 to 188 inches, depending on the wheelbase chosen. The Wayne Busette is 86 inches wide and 129.5 inches long inside.

Some states require that all buses destined for school bus use must have a 24 inch aisle for emergency exit. This is too narrow for wheelchair passage.

Crash Protection

The surroundings of the wheelchair occupant will depend on the type of bus he or she is in and the orientation of the wheelchair. In a school bus the wheelchair position will probably be near the lift. Since the lift is generally unpadded, it could cause serious injury if struck by a passenger.

Another major point of impact is the seat back. School bus seats must meet FMVSS 222 (Reference 17) and may provide the wheelchair occupant some protection, because of the padded seat back (if the wheelchair is facing forward). If the wheelchair is side facing, the occupant would incur different injuries; thus the protective system must be designed accordingly.

The interior of the transit bus is not as standardized as that of the school bus; as a result, there is a wide variety of objects that can be struck in a crash. For instance, the seats do not have any safety standards to meet, so, if struck, the severity of injury may be higher. Transit buses also have metal stanchions that could be in the trajectory of a passenger.

In a side crash, side walls and windows are the primary impact points. Also, the wheelchair itself must be kept from becoming a projectile and injuring other passengers. The wheelchair should be secured to minimize excursion. This allows the occupant to remain close to the original seating position, and away from injurious obstacles. Movement during the crash must also be considered; sudden jerks of the body or limbs can cause whiplash or similar injuries.

It should be noted that all the above discussion assumes that the wheelchair seated passenger is using a lapbelt and that the lapbelt is properly fastened and is anchored to the wheelchair axle bolt on the inside of the wheelchair structure.

Handicapped Passengers

The limitations of the handicapped occupant will be considered. Any device that requires effort by the passenger should be operable by the majority of possible

users. Section 1 above discussed types of handicaps and described the expected strength and mobility of wheelchair occupants. It was noted there that a large number of handicapped people are elderly and probably are more prone to serious injury. Unfortunately, we could find no comprehensive data on injury levels in older people, so we will use the standard injury criteria. We then will give added protection to the system, in the hope that that will take into account the extra susceptibility of the elderly.

For size and injury tolerance we will primarily design the crash protection systems for the 50th percentile adult male passenger. However, the requirements of the 5th percentile adult female and the 6-year-old child will be considered for school buses, and to these will be added the 95th percentile male for transit buses.

2.8 SUMMARY OF DESIGN GUIDELINE CHECKLIST

Using the results of the state of the art survey and the accident, injury and fatality data analysis, we compiled a series of what we feel are the evaluation criteria that could be used for evaluating crash protection systems.

The criteria include:

- Protection during normal bus operation and during accidents
  - Normal bus operation
  - Frontal impact accident
  - Side impact accident
  - Rear impact accident
- Operation from the user's point of view
  - Degree of assistance
  - Coordination/agility required
  - Complexity of securement system operation
  - Safety of securement during deployment/release operation
  - Adjustment difficulty

- Acceptability to the user
  - Comfort
  - Ease of use/evacuation

- Hazards to other occupants of the bus
  - Hazards - in use
  - Hazards - when not in use (stowed)
  - Probability of malfunction
  - Degradation with age

- Acceptability to the operators (the bus company management, not the drivers)
  - Cycle time of ingress/egress, speed of adjustment
  - Space loss and weight addition at wheelchair stations
  - Complexity and cost of bus modifications
  - Influence of the wheelchair station on bus operation
  - Probability of malfunction

- Adaptability to the wheelchair passengers and their wheelchairs
  - User size range
  - Wheelchair size range
  - Wheelchair variety range

- Adaptability to buses
  - Bus size and type (school/transit) limitations
  - Bus modification required and initial material and labor cost, complexity and precision
  - Replacement cost
  - In-use cost

SECTION 3
DECELERATION CRASH PULSE DEVELOPMENT

3.1 INTRODUCTION

This section describes a bus crash test program undertaken to determine the crash pulses of particular buses. The objectives of this effort were

- To determine the baseline deceleration crash pulses of a number of buses. (Two different impact configurations were specified for each of the selected buses.)
- To assess the performance of the forward facing occupants seated in conventional FMVSS 222 seats during the crash tests.
- To establish occupant response to the impact as a baseline for passengers in wheelchairs during the crash tests. The wheelchair location, orientation, securement system and occupant protection systems were selected to be representative of typical bus environments.
- To establish occupant response to the impact as a baseline for passengers seated on side facing seats, during the crash tests. The side facing seat location and selected environment were typical of the actual bus transportation practices.

To meet these objectives, we conducted an extensive test program of bus crash tests. Table 3-1 lists the selected test buses and the crash test configurations (speeds and modes of impact).

This section later discusses the bus crash test programs. The discussion includes descriptions of the test buses, test procedures, types of wheelchair restraints used, etc. The last subsection presents the test results.

TABLE 3-1. TEST BUSES AND IMPACT CONFIGURATIONS

No.	Bus Type	Bus Description	Test Weight (pounds)	Impact Mode	Impact Speed (mph)
1	Small school bus	Wayne "Busette," front engine	8,370	Front, Fixed Barrier	30.15
				Rear, Moving Barrier	30.19
2	Small school bus	Thomas "Mighty Mite," front engine	10,390	Front, Fixed Barrier	30.18
				Rear, Moving Barrier	29.78
3	Large transit bus	Flxible (35 foot overall length), rear engine	20,350	Front, Fixed Barrier	21.37
4	Large school bus	Carpenter conventional 66 passenger bus, front engine	15,430	Front, Fixed Barrier	21.27
				Side, Moving Barrier	30.93

TABLE 3-1. (CONT'D)

No.	Bus Type	Bus Description	Test Weight (pounds)	Impact Mode	Impact Speed (mph)
5	Large transit bus	GM "New Look" Transit Coach (40 foot overall length), rear engine	21,440	Front, Fixed Barrier	21.09
				Side, Moving Barrier	30.70
6	Large school bus	Crown Coach unitized construction school bus, underfloor engine	27,460	Front, Fixed Barrier	15.08
				Front, Fixed Barrier	21.22
				Side, 5000 pound full size passenger car	53.18
7	Large transit bus	Flxible (40 foot overall length), rear engine	22,170	Front, Fixed Barrier	21.11
8*	Large school bus	Carpenter conventional 66 passenger bus, front engine	15,270	Front, Fixed Barrier	21.12

*Test 8 was a repeat test for Test 4, in which most dummy data were lost due to an instrumentation malfunction.

3.2 SCHOOL AND TRANSIT BUS CRASH TEST PROGRAM

3.2.1 General Test Procedures Used

This subsection describes the general test procedures used in the bus crash test program. The description includes test scope, objectives, dummy placements, instrumentation, photographic coverage, etc.

3.2.1.1 Introduction and Test Requirements

The principal objective of the bus crash tests was to determine the deceleration crash pulses of the buses. These pulses will be used in later sled tests.

The tests also established a baseline for assessing crash protection effectiveness. Three areas were monitored:

- Performance and collision response of dummies seated in FMVSS 222 regulation seats (Reference 17)
- Bus structure effectiveness in securing restraint systems and securements
- Collision response of dummies occupying wheelchairs and side facing seats.

Test Scope

The bus structures were those of current unmodified vehicles. The crash test effort included two collision modes for each of two bus sizes – front and side impacts for large buses and front and rear impacts for small buses. The test speeds and conditions represented typical collision modes of moderate severity, events in which restraint and crash protection capabilities are reasonably accommodated. The input from the ongoing Caltrans-UMTA sled test program (Reference 60) provided preliminary guidelines on the effectiveness of the selected restraints and crash protection systems. Seating configurations and

securements were selected to represent the actual practice in school and transit bus intracity transportation of handicapped passengers.

Test Requirements

The test vehicles were left structurally unmodified, with their frames, drivetrains, suspensions and body elements in their as-manufactured states. Almost all of the test buses contained seven seated instrumented dummies (six passengers and one driver). The only exceptions were the tests in which the driver dummy was uninstrumented and only photographic coverage was obtained.

We designed the on-board instrumentation and fixtures to be compatible with both the front and the side/rear test modes. The vehicle was first subjected to a front perpendicular barrier crash test. After the post-test measurements were taken, the test apparatus (including dummies) was then prepared for a side or rear impact. In the side and rear impacts the vehicles were struck by a 4000 pound moving barrier or, in one case, by a full size automobile.

Test Data and Their Use to Meet the Test Objectives

Deceleration Pulses. These tests provided baseline deceleration crash pulse profiles for each bus type. The deceleration pulse profiles and corollary structural response data (i.e., local buckling or structural failure in the restraint and securement systems) were used in the sled test crash simulation and development programs. Triaxial accelerometers monitored the decelerations along the longitudinal centerline of the bus floor; this allowed an analysis of deceleration as a function of longitudinal location in the bus. Biaxial accelerometers were placed on the floor of the bus, near the passenger seating positions; these allowed us to determine the effects of lateral location on the deceleration event.

FMVSS 222 Seats (Reference 17). During the impact tests we examined the crash response and containment capability of the FMVSS 222 compliant school bus seat. Dummy acceleration data established the baseline severity index, while

deflection and structural failure information established the environmental integrity of current school bus interiors.

Deformation Data. The deflections and deformations of the test vehicle structure under impact loading showed the intrusion characteristics of the test buses. The deflection data highlighted the areas of severe occupant vulnerability. We used failures or deflections of the bus structure at securement points of the interior compartments to define the design criteria for restraint system integrity and performance.

3.2.1.2 Dummy Sizes and Locations

The inclusion of various sizes and types of instrumented anthropomorphic dummies at different seat locations provided data indicative of dimensional and anthropometric influences on crash protection. The dummy types represented the elementary, intermediate and high school pupils for school buses and children and adults for transit buses. The dummies occupied front facing seats, side facing seats and wheelchairs to duplicate the typical mix of occupants on special care school buses and on transit buses.

Each bus contained seven dummies:

- One 50th percentile male driver
- One 6-year-old child and one 50th percentile adult male in the same conventional forward facing seat
- Two dummies, in various combinations from the 6-year-old child to the 95th percentile adult male, in side facing seats
- Two 50th percentile adult males in wheelchairs.

The typical dummy locations are shown in Figures 3-1 and 3-2. The driver dummy was always restrained with a lap belt. This dummy was instrumented in all large bus tests for head, chest accelerations and belt loads.

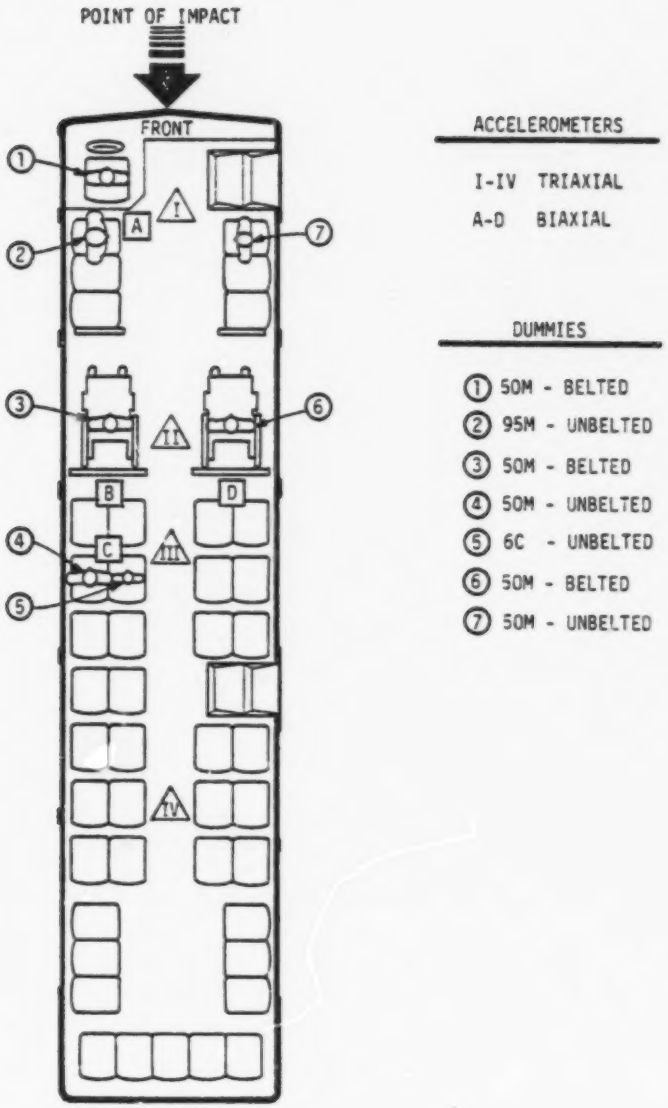


FIGURE 3-1. DUMMY AND ACCELEROMETER LOCATIONS IN A TYPICAL FRONT IMPACT TEST

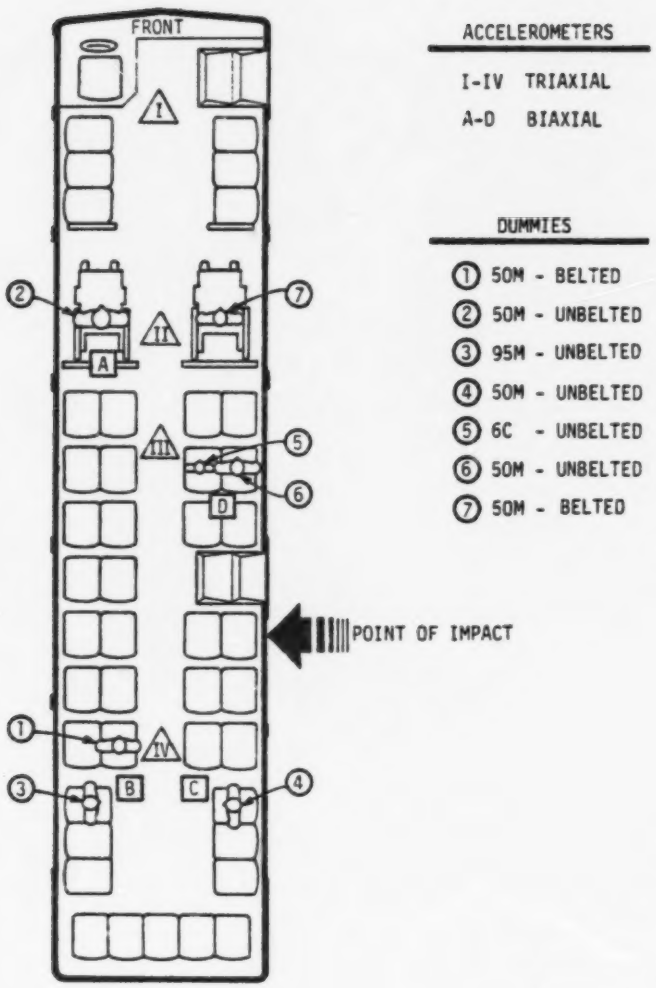


FIGURE 3-2. DUMMY AND ACCELEROMETER LOCATIONS IN A TYPICAL SIDE IMPACT TEST

The two dummies in the conventional forward facing seat were restrained with seat belts in the first two tests. They were left unbelted in the remaining tests. When they had belts, the head and chest accelerations and belt loads were measured. Without belts, the head and chest accelerations were measured for both dummies, but femur loads were measured only for the 50th percentile adult male dummies.

The two side facing dummies were placed either side by side or facing each other on opposing side facing seats. These dummies were belted in two of the tests of small school buses. At that time, chest and head accelerations and belt loads were monitored. In the remaining tests, the dummies were left unbelted; the head and chest accelerations were measured for both, but femur loads were measured only for the 50th percentile males.

The wheelchair seated dummies were 50th percentile dummies in all tests. They were belted with a lap belt secured to the axle bolts of the wheelchair. The head and chest accelerations and belt loads were measured for all of them.

3.2.1.3 Dummy Instrumentation

Table 3-2 summarizes the monitoring of the transducers.

Other Transducers and Photographic Coverage

Each test included

- One biaxial accelerometer under each of the seating positions
- Four (0 to 50 G) triaxial accelerometers on the bus floor in selected positions
- Eight high speed (1000 frames/sec) 16mm cameras inside the bus, ceiling mounted
- Two high speed (1000 frames/sec) 16mm cameras outside the bus
- One real-time camera outside the bus
- Speedometer on impacting vehicle for impact speed
- Event marker on the impacting vehicle

TABLE 3-2. MONITORING OF DUMMY TRANSDUCERS

Dummy Number Per Figure 3-1	Head Triaxial	Chest Triaxial	Femurs	Belts
1	3 channels	3 channels		2 channels
2	3 channels	3 channels		
3	3 channels	3 channels		2 channels
4	3 channels	3 channels	2 channels	
5	3 channels	3 channels		
6	3 channels	3 channels		2 channels
7	3 channels	3 channels	2 channels	

Accelerometer Locations

Typical accelerometer positions are illustrated in Figures 3-1 and 3-2. Four triaxial accelerometers were affixed to the bus floor along the longitudinal centerline. One was located in the front of the passenger compartment, and one at the rear of the passenger compartment. The remaining two accelerometers were attached to the bus frame rail midway between the front and rear of the chassis. Four biaxial accelerometers were mounted in the x-z plane of the bus and were used to determine the accelerations transmitted to the passenger seating positions. One biaxial accelerometer was attached to the bus floor beneath the rearmost of the two forward facing passenger seats at the middle of the bus, and one was located beneath the driver's seat. Biaxial accelerometers were affixed to the bus floor as near as possible to the mounting positions of each of the two wheelchair securement mechanisms.

Test Description

Frontal Rigid Barrier Impact. The test vehicles struck a rigid barrier. The front impacts simulated "head on" collisions – the flat barrier face was perpendicular to the test vehicle's line of travel. The test speeds are indicated in Table 3-1 above.

Moving Side and Rear Barrier Impact. After the completion of the front barrier test, the bus's interior components were prepared for a second test (as mentioned above). The vehicle was then submitted to a side or rear impact by either a 4000 pound moving barrier or a full size passenger car.

Photographic Coverage

Seven ceiling-mounted, high speed (1000 frames/sec) 16mm cameras were installed in each test vehicle in positions dictated by the interior bus dimensions and the lens angle. Three cameras were also located outside the bus. Two were high speed (1000 frames/sec) cameras providing a pan view of the vehicle crush; the other was a real-time camera which covered the vehicle approach and crush. Typical camera positions in the tests are shown in Figures 3-3 and 3-4.

Test Data to be Acquired

After each crash test, a "quick look" package of data was available as a check on the success of the test run. This package included

- A confirmation that the data were recorded
- A check of selected channels to assure that the data recorded were reasonably correct quantitatively.

For each dummy the following information was developed (depending on the number of transducers used):

- Head deceleration pulses as a function of time; three components and the resultant were included
- Head Injury Criteria (HIC) number (Reference 91)
- Chest deceleration pulses as a function of time; three components and the resultant were included
- Chest Severity Index (CSI) (Reference 92)
- Two femur loads as a function of time
- Belt loads as a function of time

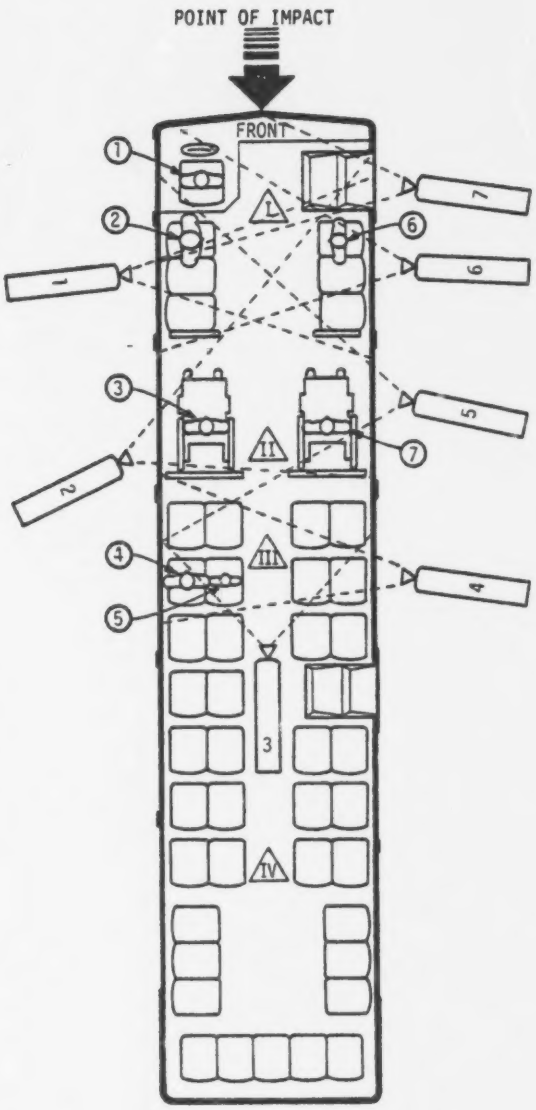


FIGURE 3-3. CAMERA LOCATIONS IN A TYPICAL FRONT IMPACT TEST

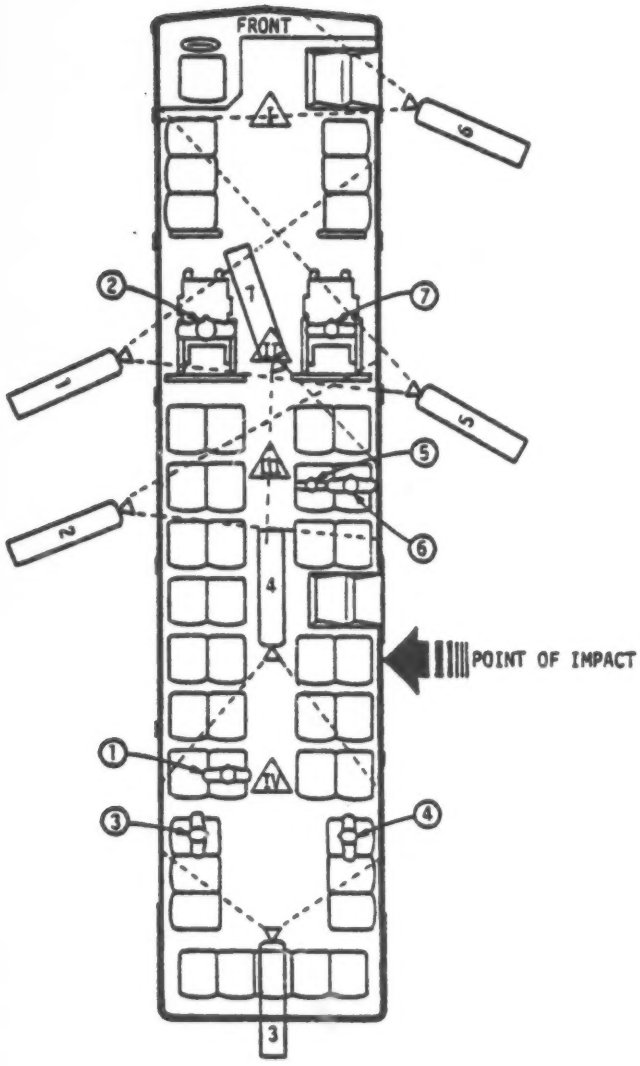


FIGURE 3-4. CAMERA LOCATIONS IN A TYPICAL SIDE IMPACT TEST

All structural accelerometer data were presented as time plots of the component and resultant accelerations and were identified by transducer location.

The photographic coverage included

- Pre- and post-test colored still pictures of the bus interior and exterior from a number of angles
- High speed movies (seven cameras inside and two outside the bus), including both timing and event marks
- Real-time movies
- Measurements and documentation of static vehicle crush at the impact points
- Measurements and documentation of structural deflections of both the bus structure and the interior components.

Measurements

Measurements were made of the following:

- Dummy head acceleration (lateral, longitudinal and vertical)
- Dummy chest acceleration (lateral, longitudinal and vertical)
- Femur loads for one 222 seated dummy and one side facing dummy
- Seat belt loads for the driver and wheelchair-seated dummies
- Structural acceleration under designated seating positions (lateral and longitudinal)
- Structural acceleration of the bus floor at front, mid and rear compartment positions and frame acceleration at the midpoint (all lateral, longitudinal and vertical components)
- Impact speed.

Pre-Test/Post-Test Reference Measurements

General reference points for measuring positions in the bus interior are longitudinally from the front limit to the passenger compartment, laterally from

the bus center and vertically from the bus floor. The positions of both the dummies in the seats and their dynamic contact surfaces were measured relative to the manufacturers' seating reference points.

Pre-test measurements included

- Seat positions
- Seat back angles
- Dummy positions (relative to seats, using reference markers and targets)
- Positions of potential contact surfaces
- Wheelchair orientation and positions (measured via the locations of the axle centers)
- Position of dummies in wheelchairs (relative to the wheelchair, using reference markers and targets)
- Distance from the bus reference point to the selected reference points on the cowl
- Points of contact of the wheelchair securement system.

Post-crash measurements included the first seven above, plus

- Wheelchair deformation
- Bus external deformation (depth and extent of deformed surfaces)
- Bus interior deformation.

3.2.1.4 Documentation and Log

Standard documentation and logging procedures were followed to ensure that

- The test data were readily available and could be cross-checked with photographic coverage.
- The locations of transducers, cameras, etc., were properly documented.
- Any unusual events and occurrences with respect to vehicle, dummies, instrumentation, cameras, etc., before, during and after the actual test were noted and brought to the attention of the test engineer responsible for the test.

- The dummies were checked before and after each test to make sure there was no damage to dummies or instrumentation.

3.2.2 Test Parameters

The rationale used for the selection of the test parameters was based on the

- Use of realistic transportation practices
- Maximization of the data generated (by avoiding duplication of parameters)
- Representation of moderate to severe types of accidents.

The individual test parameters are described in the following subsections.

3.2.2.1 Types of Buses

Table 3-1 above lists the buses tested during the program. The selections of the bus types were based on the results of the state-of-the-art survey. The survey indicated that, in general, all types of school and transit buses can be equipped and used for the transportation of handicapped passengers. Table 3-3 shows a broad classification of the buses that are used in the transportation of the handicapped. A comparison of Tables 3-1 and 3-3 shows that our test matrix covered all the classifications included in Table 3-3, except for the small transit bus, which was left out because it was felt that it could be represented by the small school bus. To summarize, the test matrix included the following variations:

- School and transit buses
- Front, rear and underfloor engine locations
- Small, medium and large size buses
- Separate chassis/body and unitized chassis/body construction.

The actual selection of the test buses was governed by the availability of a suitable bus in each classification. Two small school buses were equipped with lifts when tested. None of the other buses were equipped with either a lift or a

BLANK

PAGE

TABLE 3-3. OVERALL CLASSIFICATION OF BUS TYPES

No.	Bus Type	Weight Range (pounds)	Overall Length (feet)	Seated Passenger Capacity Range	Wheelchair Entry
1	Small school bus	6,000-8,000	10-14	8-16	ramp/lift
2	Medium size school bus	8,000-12,000	16-24	16-24	ramp/lift
3	Full size, conventional school bus, separate chassis/body construction	12,000-17,000	32-36	60-72	lift
4	Large, Unitized	28,000-32,000	32-36	66-97	lift
5	Small transit bus	8,000-12,000	16-24	10-14	lift
6	Large transit bus	22,000-34,000	35-40	35-40	lift

ramp. Nevertheless, the dummy locations were selected as representative of seating arrangements used in the transportation of the handicapped. The test buses are shown in Figures 3-5 through 3-12.

3.2.2.2 Types of Wheelchair Securements Used

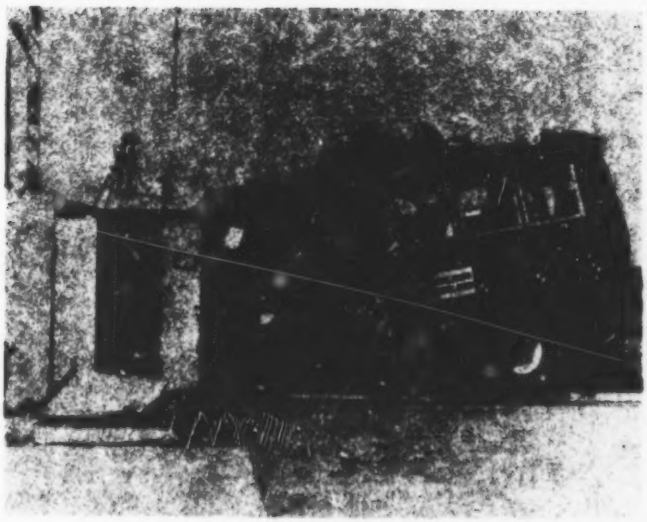
Devices used for wheelchair securement inside the bus can be grouped into five basic generic types. These were discussed in Section 1 of this report.

The wheelchair securement devices used during the crash tests were selected to include a large variation of commercially available wheelchair securement types. Table 3-4 lists the devices used; the individual devices are described below.

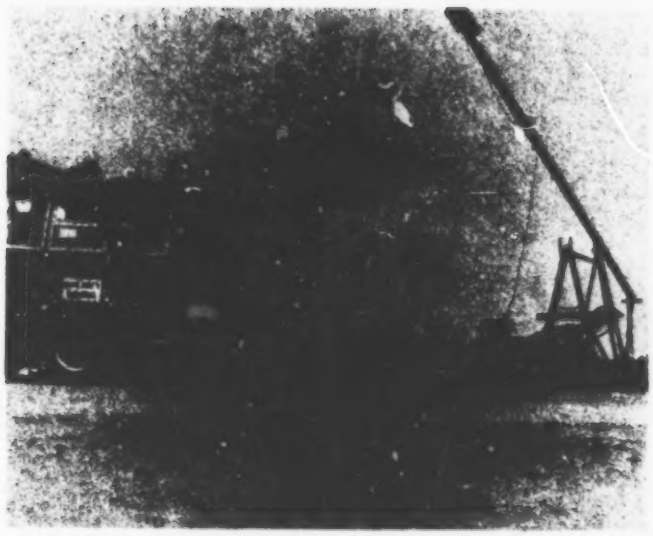
1. Wayne Busette Test – Figures 3-13 and 3-14 show the two wheelchair securements used in the Wayne Busette test. Figure 3-13 shows the side facing wheelchair against the left wall of the bus. The wheelchair was secured by two wall mounted rim pins passing through the wheelchair rims at axle level. Figure 3-14 shows the rear facing wheelchair that was secured by rim pins at axle level. The stanchion behind the wheelchair is padded to absorb energy from any head impacts.

2. Thomas Mighty Mite Test – Figure 3-15 shows the side facing wheelchair in the rear left corner of the bus. The wheelchair was secured by wall mounted rim pins. Figure 3-16 shows the forward facing wheelchair. This forward facing wheelchair was secured by floor mounted, floor level rim pins and was located in the right rear corner of the bus.

3. Flxible 35-foot Transit Bus Test – There was only one wheelchair during this test. It was placed forward facing on the right side of the bus. The wheelchair securement system consisted of two brackets, one on either side of the bus, that mated with a flat plate attached to the T-junction of the wheelchair structure. A pin passed through holes in the bracket and the plate to secure the wheelchair. This arrangement (shown in Figure 3-17) was designed and tested by Caltrans (Reference 60).

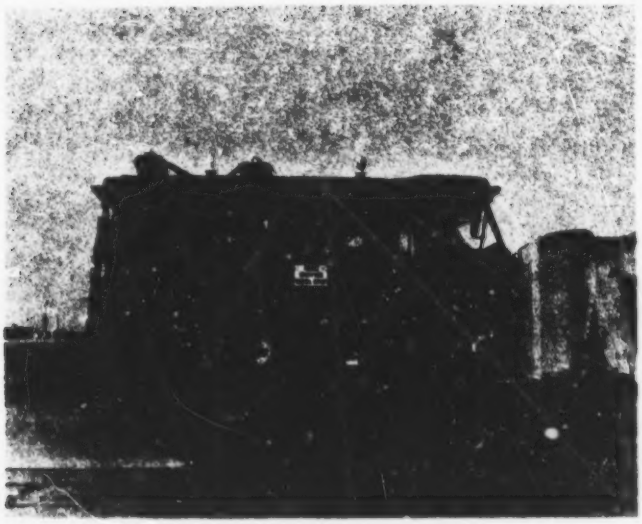


FRONT IMPACT



REAR IMPACT

FIGURE 3-5. WAYNE BUSETTE – SMALL SCHOOL BUS IMPACT TESTS



FRONT IMPACT

REAR IMPACT

FIGURE 3-6. THOMAS MIGHTY MITE – SMALL SCHOOL BUS IMPACT TESTS

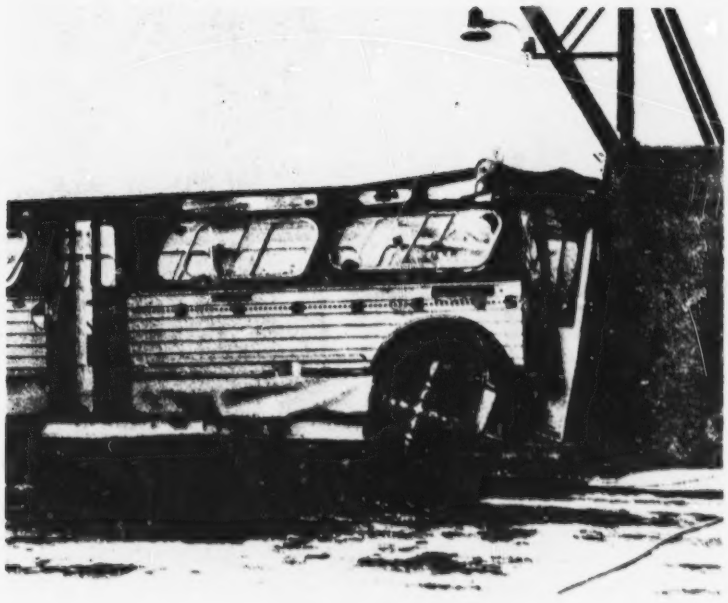
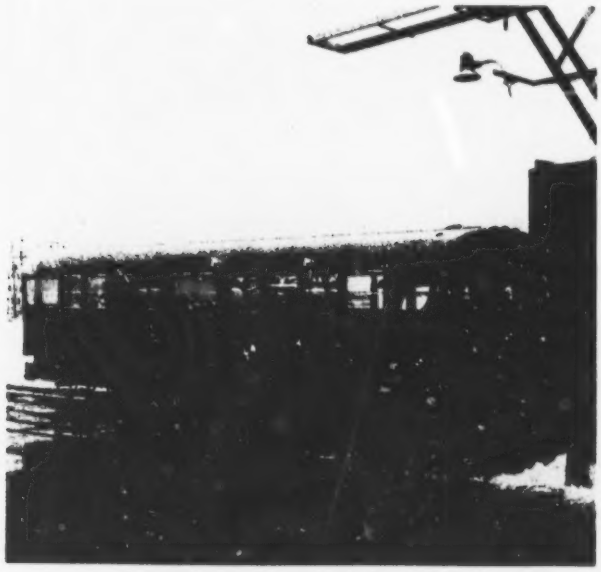


FIGURE 3-7. FLXIBLE 35 FOOT TRANSIT BUS FRONT IMPACT TEST

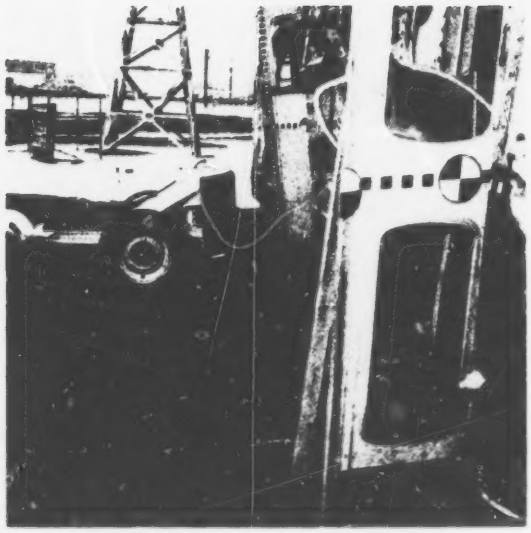


FRONT IMPACT

SIDE IMPACT

FIGURE 3-8. CARPENTER CONVENTIONAL 66-PASSENGER SCHOOL BUS IMPACT TESTS

FRONT IMPACT

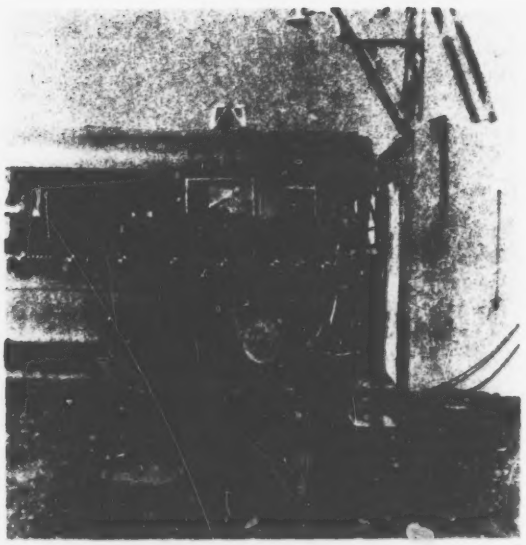


SIDE IMPACT

FIGURE 3-9. GENERAL MOTORS 40 FOOT TRANSIT BUS IMPACT TEST

FRONT IMPACT

FRONT IMPACT



SIDE IMPACT

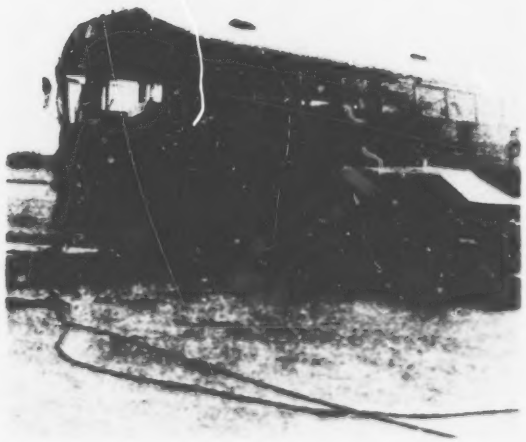


FIGURE 3-10. CROWN COACH UNITIZED CONSTRUCTION
LARGE SCHOOL BUS IMPACT TESTS

FIGURE 3-11. FLXIBLE 40 FOOT TRANSIT BUS FRONT IMPACT TEST

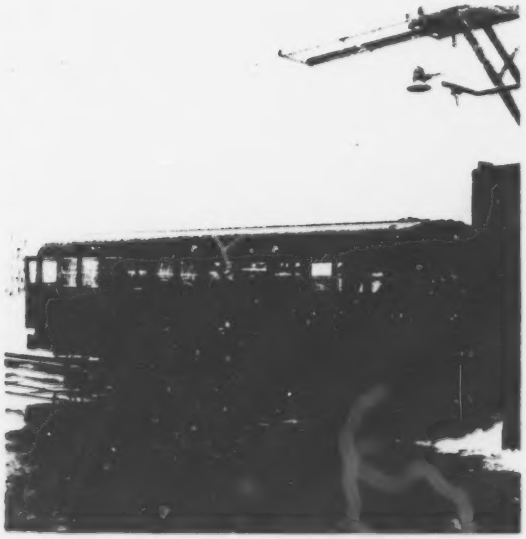


FIGURE 3-12. CARPENTER CONVENTIONAL 66-PASSENGER SCHOOL BUS FRONT IMPACT TEST

TABLE 3-4. WHEELCHAIR SECUREMENT DEVICES USED DURING BUS CRASH TESTS

Test No.	Test Bus	Wheelchair Securement Device	Wheelchair Orientation
1	Wayne Busette	1. Wall mounted rim pin, axle level	Side facing
		2. Floor mounted rim pin. axle level	Rear facing
2	Thomas Mighty Mite	1. Wall mounted rim pin, axle level	Side facing
		2. Floor mounted rim pin, floor level	Forward facing
3	Flxible 35 foot transit bus	1. Pin going through a plate secured at T-junction	Forward facing
4	Carpenter conventional size school bus	1. Pin going through a plate secured at T-junction	Side facing
		2. Pedestal mounted adjustable prongs at axle level	Forward facing
5	GM transit bus	1. American Seating with a three-point belt system	Forward facing
		2. Collins system with lap belt	Forward facing
6	Crown Coach unitized school bus	1. Aeroequip belt system	Side facing
		2. Aeroequip belt system	Forward facing
7	Flxible 40 foot transit bus	1. Flxible with lap belt	Forward facing
		2. American Seating without three-point belt	Forward facing
8	Carpenter conventional size school bus	1. Flxible without lap belt	Forward facing
		2. Collins without lap belt	Forward facing

FIGURE 3-13. RIM PIN SECUREMENT SYSTEM FOR SIDE FACING WHEELCHAIR IN THE WAYNE BUSETTE

FIGURE 3-14. RIM PIN SECUREMENT SYSTEM FOR REAR FACING WHEELCHAIR IN THE WAYNE BUSETTE

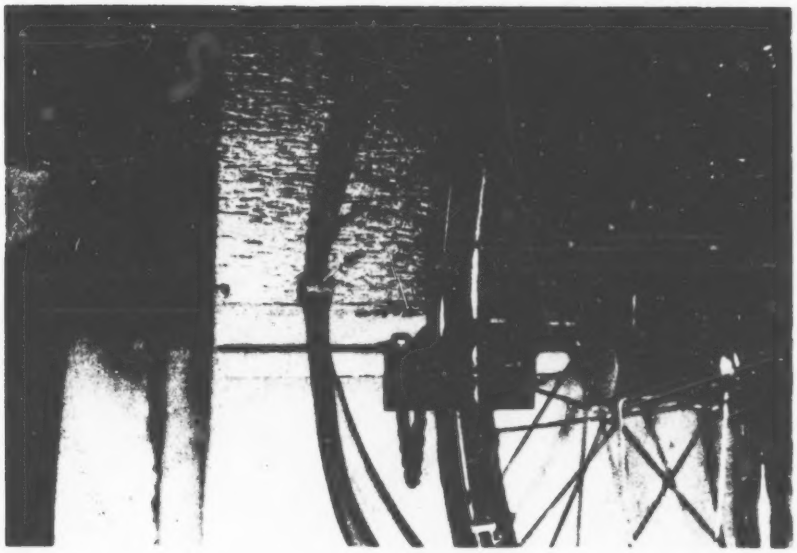


FIGURE 3-15. RIM PIN SECUREMENT SYSTEM FOR SIDE FACING WHEELCHAIR IN THE THOMAS MIGHTY MITE

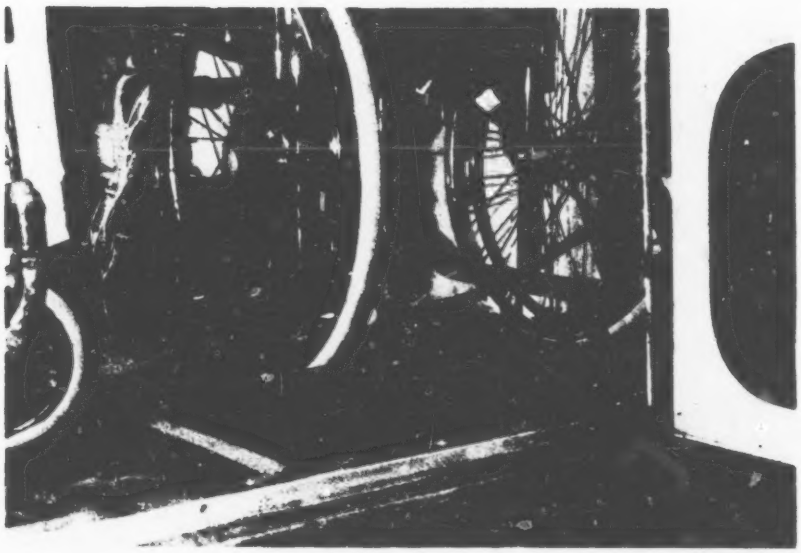


FIGURE 3-16. RIM PIN SECUREMENT SYSTEM FOR FORWARD FACING WHEELCHAIR IN THE THOMAS MIGHTY MITE

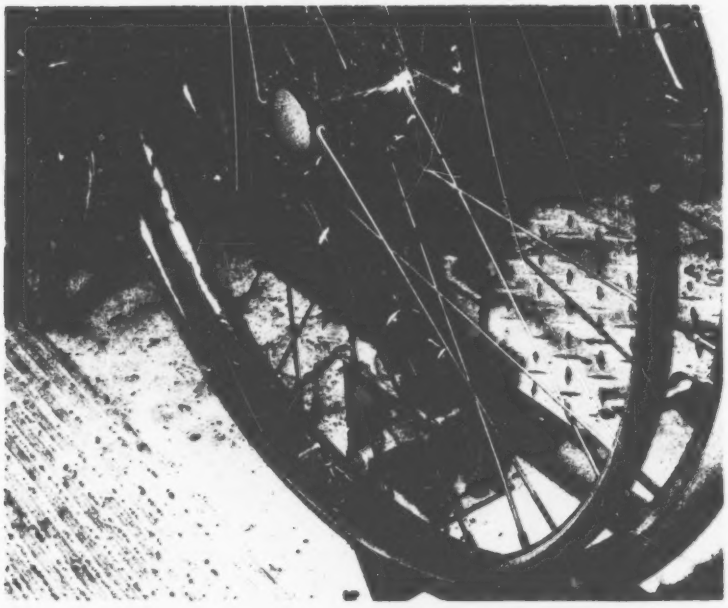


FIGURE 3-17. FORWARD FACING WHEELCHAIR SECURED AT T-JUNCTION IN THE FLXIBLE 35 FOOT TRANSIT BUS

4. Carpenter Conventional Size School Bus Test – Figure 3-18 shows the side facing wheelchair secured with the same device that was shown in Figure 3-17. Figure 3-19 shows the wheelchair securement used for the forward facing wheelchair. The device used was manufactured by Carpenter Body Works. It consists of a transverse bar mounted on the floor. The transverse bar has two sliding parts which can be locked at selected locations. Each sliding part has a prong attached to it; the prong passes through the wheelchair rim to secure it.

5. GM Transit Bus Test – Figure 3-20 shows the American Seating system used at the left side wheelchair station. The system includes a special flip-up transverse seat at the wheelchair station. The wheelchair is secured by a clamp which is exposed when the seat is pushed up. The clamp holds the left wheel only; it is deployed when the wheelchair wheel strokes the flat plate. The release of the clamp is achieved by pushing down on the lever. The three-point belt system was also used during this test. Figure 3-21 shows the Collins Industries wheelchair securement system used at the right side wheelchair station. It

consists of a special single flip-up seat which has special clamps on either side of the seat; the clamps are exposed when the seat cushion is pushed up. A wheelchair backs into the clamps that are deployed and secure the wheelchair at both wheels. A lap belt provided with the system was used during the test.

6. Crown Coach Unitized School Bus Test – Floor mounted aeroquip cargo belt arrangements were used during this test. Figures 3-22 and 3-23 show the two arrangements employed for the side facing and the forward facing wheelchairs, respectively. Several variations of this type of wheelchair securement are widely used in school and transit bus transportation of the handicapped.

7. Flxible "40-foot" Transit Bus Test – Figure 3-24 shows the wheelchair securement system marketed by Grumann Flxible. It consists of a flip-up seat mounted longitudinally with a barrier mounted transversely at the wheelchair station. A padded adjustable bar is exposed when the longitudinal seat cushion is pushed up. This bar can be deployed, adjusted and locked to be in front of the wheelchair (as shown in Figure 3-24). The barrier behind the wheelchair also provides a lap belt, which was used during this test. The other wheelchair in this test was secured with the American Seating system described earlier (and shown in Figure 3-20). However, during the present test the three-point belt system was not used (Figure 3-25).

FIGURE 3-18. SIDE FACING WHEELCHAIR SECURED AT T-JUNCTION IN THE CARPENTER SCHOOL BUS

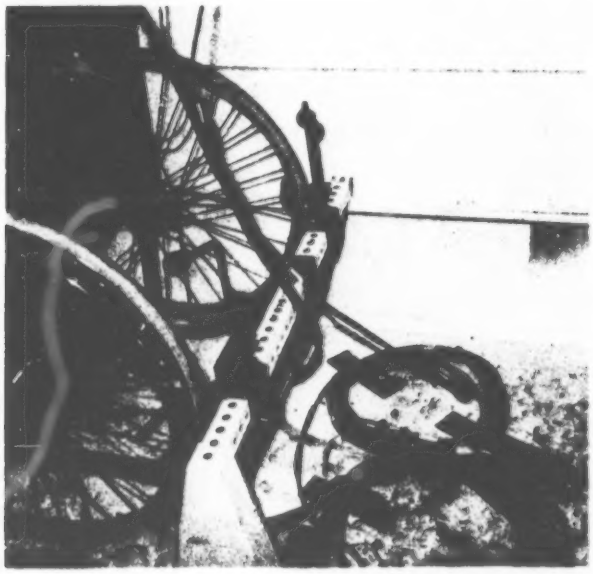


FIGURE 3-19. FORWARD FACING WHEELCHAIR SECURED AT WHEEL RIMS IN THE CARPENTER SCHOOL BUS

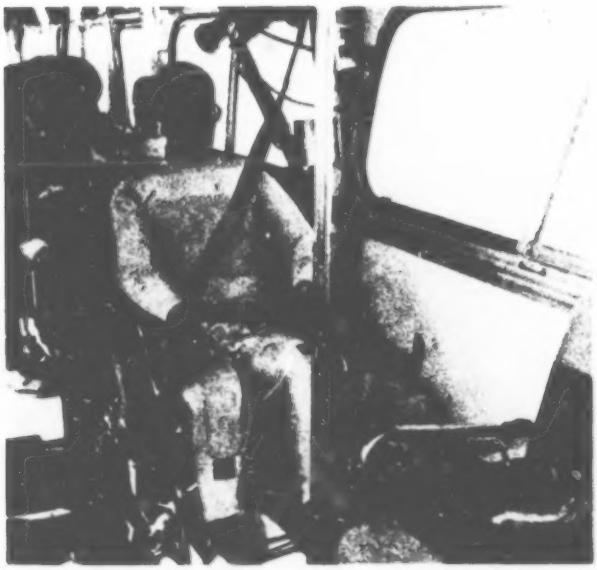


FIGURE 3-20. AMERICAN SEATING SYSTEM WITH THREE-POINT BELT SYSTEM IN THE GM TRANSIT BUS

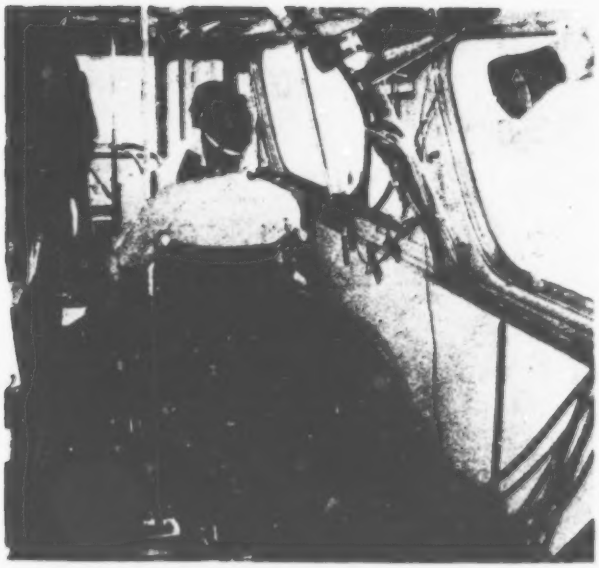


FIGURE 3-21. COLLINS SAF-T-LOCK SYSTEM WITH LAP BELT IN THE GM TRANSIT BUS

FIGURE 3-22. AEROQUIP TIEDOWNS FOR SIDE FACING WHEELCHAIR IN THE CROWN COACH SCHOOL BUS

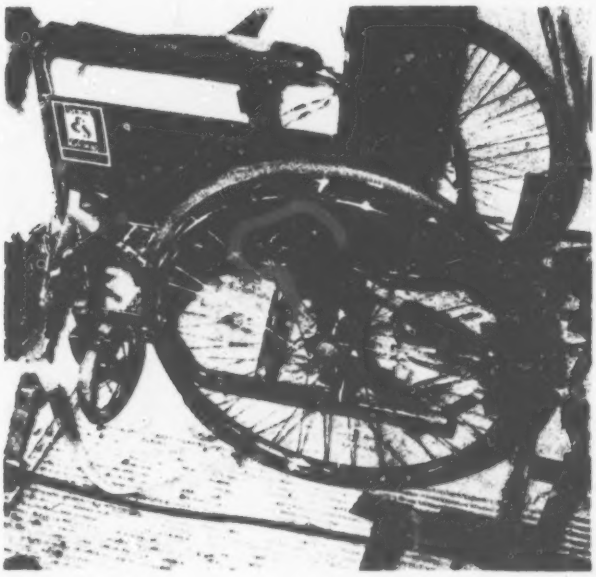


FIGURE 3-23. AEROQUIP TIEDOWNS FOR FORWARD FACING WHEELCHAIR IN THE CROWN COACH SCHOOL BUS

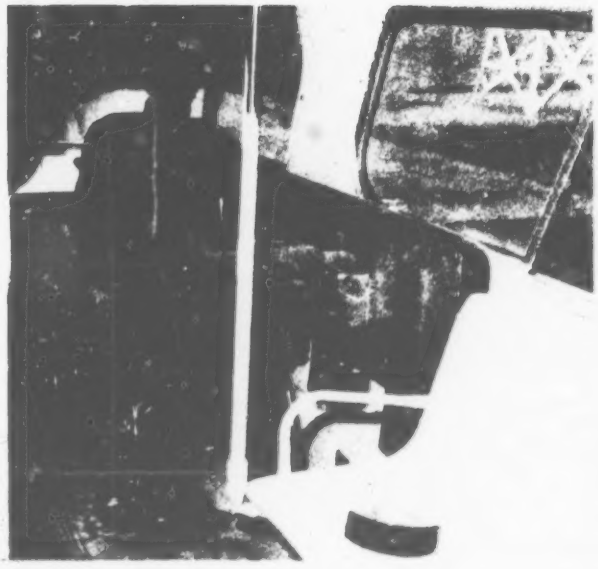


FIGURE 3-24. FLXIBLE SYSTEM WITH LAP BELT IN THE FLXIBLE BUS

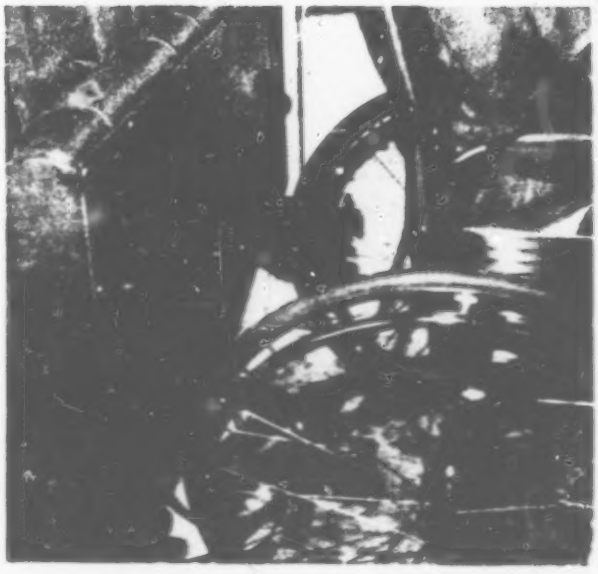


FIGURE 3-25. AMERICAN SEATING SYSTEM WITHOUT THREE-POINT BELT IN THE CROWN COACH SCHOOL BUS

8. Carpenter Conventional Size School Bus Test – During this test the Flxible system was used without the lap belt, as shown in Figure 3-26. The other system was the Collins system without lap belts (Figure 3-27).

3.2.2.3 Wheelchair Types and Orientations

In these tests the wheelchairs used were Everest and Jennings Model T8A (250-260) (Reference 2). This is one of the most common type of wheelchair in use today. It is manually operated and is equipped with footrests and armrests.

A wide variety of wheelchair orientations and locations was used during the bus crash tests. All the locations and orientations were representative of actual practices followed by transit and school bus operators. The wheelchair orientations and locations are listed in Table 3-5.

3.2.2.4 Test Speeds and Crash Configurations

Table 3-1 shows the speeds and crash modes of the individual buses. The two smaller buses were tested in the front mode and then in the rear mode. The remaining larger buses were tested in the front mode and then the side mode. The front crashes were conducted against a barrier, while the side and rear crashes were done with a standard movable barrier simulating a 4000 pound car. In one case a full size passenger car was used.

Because of the weight of the large buses, it was felt that a rear crash would have little effect. As a result, the large buses were tested in the side mode, since this type of impact would affect the bus to a greater degree. Both the rear and the side modes simulate typically occurring accidents.

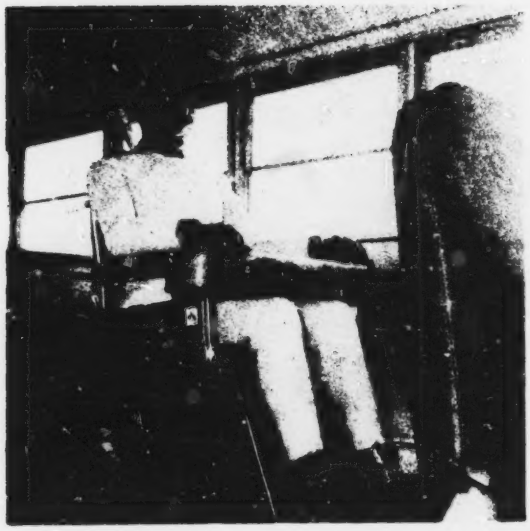


FIGURE 3-26. FLXIBLE SYSTEM WITHOUT LAP BELT
IN THE CARPENTER SCHOOL BUS

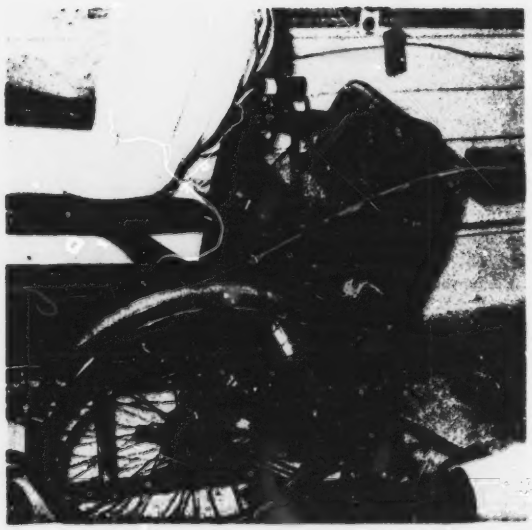


FIGURE 3-27. COLLINS SYSTEM WITHOUT LAP BELT
IN THE CARPENTER SCHOOL BUS

TABLE 3-5. ORIENTATIONS AND LOCATIONS OF WHEELCHAIRS

Test No.	Test Bus	Wheelchair Orientation	Wheelchair Location
1	Wayne Busette	Side facing	Left front, behind the driver
		Rear facing	Right front, next to the forward entrance
2	Thomas Mighty Mite	Side facing	Left rear corner
		Forward facing	Right rear corner
3	Flxible 35 foot transit bus	Forward facing	Right transit bus wheelchair station
4	Carpenter conventional size school bus	Side facing	Left front, behind the driver
		Forward facing	Right side, behind the wheelchair lift position
5	GM transit bus	Forward facing	Left transit bus wheelchair station
		Forward facing	Right transit bus wheelchair station
6	Crown Coach unitized school bus	Side facing	Left front, behind the driver
		Forward facing	Right front, behind the first seat
7	Flxible 40 foot transit bus	Forward facing	Left transit bus wheelchair station
		Forward facing	Left side, opposite the bus exit
8	Carpenter conventional size school bus	Forward facing	Left front, behind the driver
		Forward facing	Right front, next to the front entrance

3.2.3 Bus Crash Test Results

3.2.3.1 Introduction

This subsection presents significant resuls from the bus crash tests. A massive amount of data was collected from all the bus tests. The full test reports on all bus tests are included in Appendices E, F and G. Subsection 3.2.3.2 discusses the deceleration crash pulses for individual test buses. The discussion includes deceleration profiles at different stations inside the test bus. Also presented are composite test pulses for usage for sled tests. Subsection 3.2.3.3 describes the characteristics of structural deformation for each test bus. Subsection 3.2.3.4 presents typical dummy trajectories and impact points. Data collected from these analyses are useful in establishing requirements for occupant protection systems. Subsection 3.2.3.5 summarizes injury levels that were experienced by the test dummies. The injury levels are presented in terms of generally established injury criteria in terms of head/chest accelerations, and femur/belt loads. Additionally, unusual dummy excursions, impacts and head/neck rotations also are commented upon. Finally, Subsection 3.2.3.6 presents additional information wherein wheelchair securement systems, some derived pulses, repeatability of the results, etc. are discussed.

3.2.3.2 Deceleration Crash Pulses

Crash Pulses from Different Buses

Wayne Busette – Frontal Impact (Fixed barrier at 30 mph). The representative pulse of this bus has a basic trapezoidal shape. The rise time is about 25 msec with a constant value of about 15 Gs. The duration of the constant value is approximately 50 msec with a total duration of 160 msec. There is an initial spike due to the initial impact and a second rise probably due to the engine mass (Figures 3-28 and 3-29).

Wayne Busette – Rear Impact (Moving barrier at 30 mph). The shape is similar to the front impact but with a shorter duration. The rise time is 14 msec to a plateau value of about 16 Gs. The duration of the plateau is

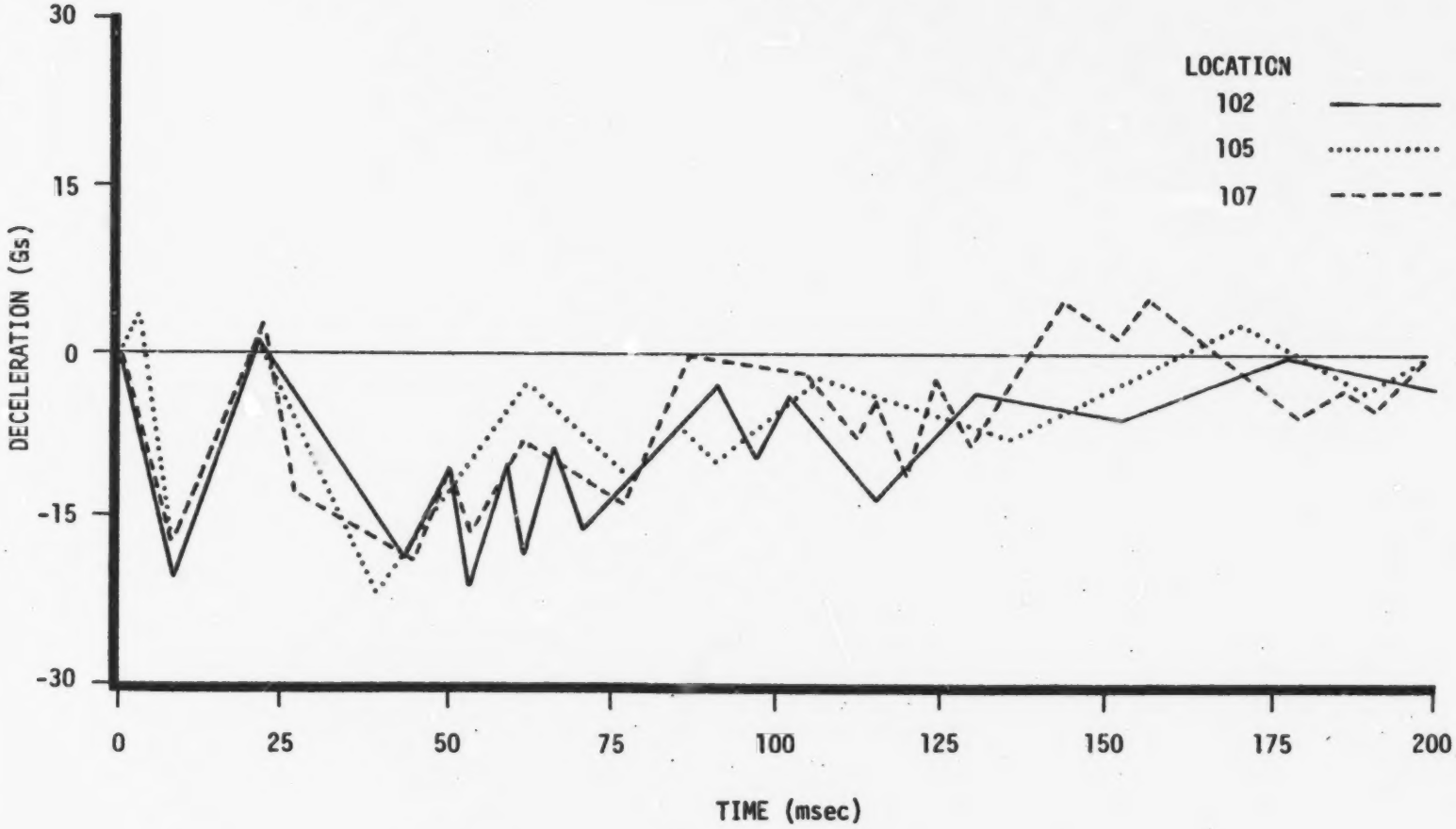
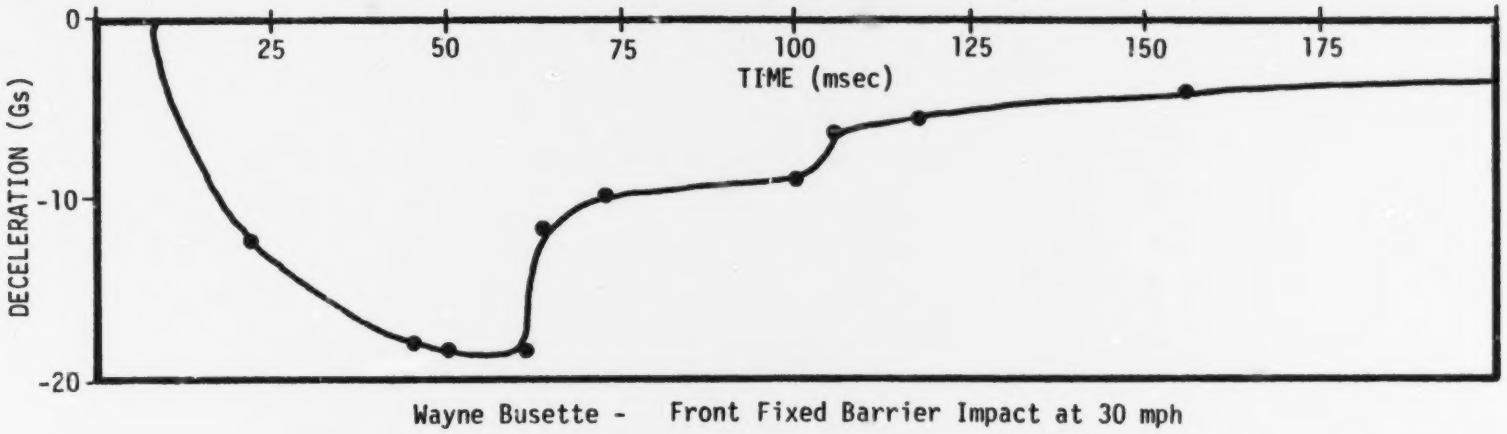
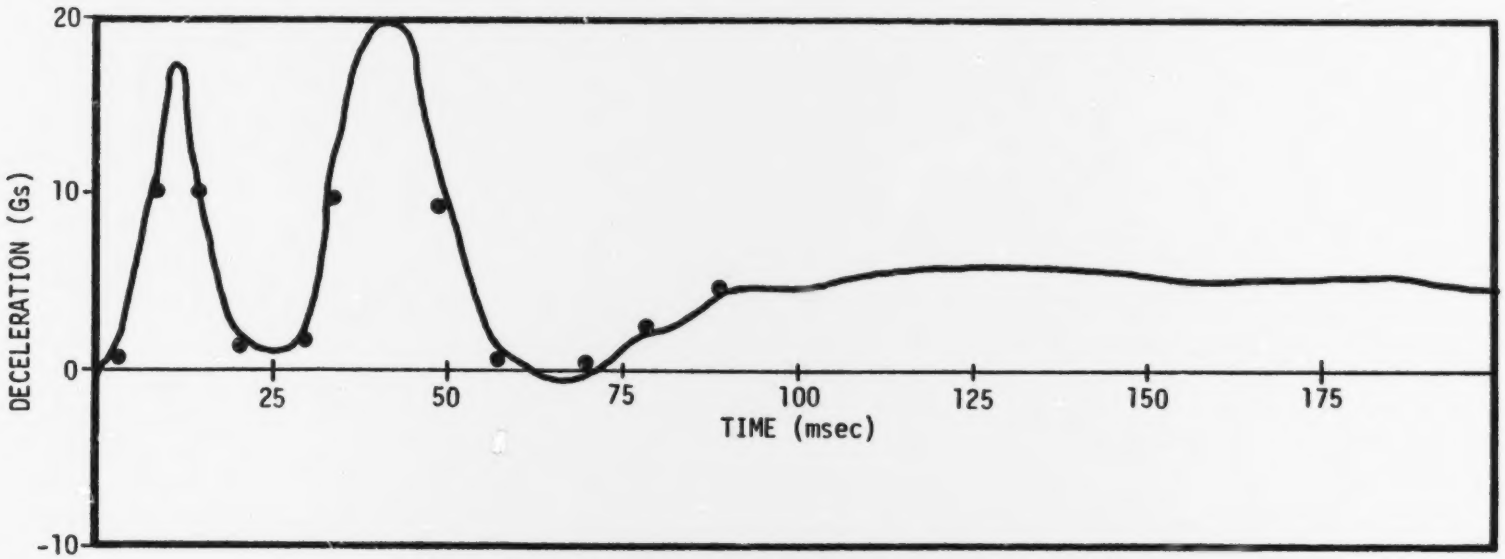


FIGURE 3-28. WAYNE BUSETTE FRONT IMPACT LONGITUDINAL DECELERATIONS



Wayne Busette - Front Fixed Barrier Impact at 30 mph



Wayne Busette - Rear Moving Barrier Impact at 30 mph

FIGURE 3-29. WAYNE BUSETTE COMPOSITE CRASH PULSES

24 msec, and the total duration is 55 msec. This pulse also has an initial spike with a sudden dropoff – attributed to the bumper impact and the buckling of the frame members (Figures 3-29 and 3-30).

Thomas Mighty Mite Bus – Frontal Impact (Fixed barrier at 30 mph). The trapezoidal shaped pulse rises to its plateau value of about 19 Gs in 30 msec. The total duration and the duration of the plateau are about 150 msec and 70 msec, respectively. This pulse is similar to the Wayne pulse, except it does not have the same high initial peak. The even rise is consistent with a more uniform deformation of the bus (Figures 3-31 and 3-32).

Thomas Mighty Mite School Bus – Rear Impact (Moving barrier at 30 mph). Another trapezoidal pulse. This has a very fast rise time of 10 msec. The plateau value reached is 13 Gs, with short spans of 30 and 50 msec for the plateau duration and the total duration, respectively. It has a high initial peak similar to the Wayne rear pulse (Figures 3-32 and 3-33).

GM Transit Bus – Frontal Impact (Fixed barrier at 21 mph). This pulse has a general trapezoidal shape except for the initial spike. The spike rises to 18 Gs before settling down to a plateau value of 7 to 8 Gs. The duration of the plateau is 70 msec, while the total is 150 msec. The sharp spike of the initial impact tapers out as the buckling of the bus begins (Figures 3-34 and 3-35).

GM Transit Bus – Side Impact (Moving barrier at 30 mph). This pulse consists of two major spikes. The initial spike rises to 30 Gs in 4 msec. The second spike starts at 18 msec and rises a little slower to 21 Gs, then tapers off to a rebound value of 5 Gs. The total duration of the two spikes is 50 msec. These spikes are due to two stiff structural members in the crush zone (Figures 3-35 and 3-36).

Carpenter School Bus – Frontal Impact (Fixed barrier at 30 mph). This is a general trapezoidal pulse with an initial spike and dropoff. The spike rises to 12 Gs in 5 msec. The rise to the plateau value of 9 Gs takes 8 msec from the dropoff. The spans of the plateau and of the total duration are 120 msec and 175 msec, respectively. The double rise at the beginning appears to be due to the bumper structure collapse and the engine impact (Figures 3-37 and 3-38).

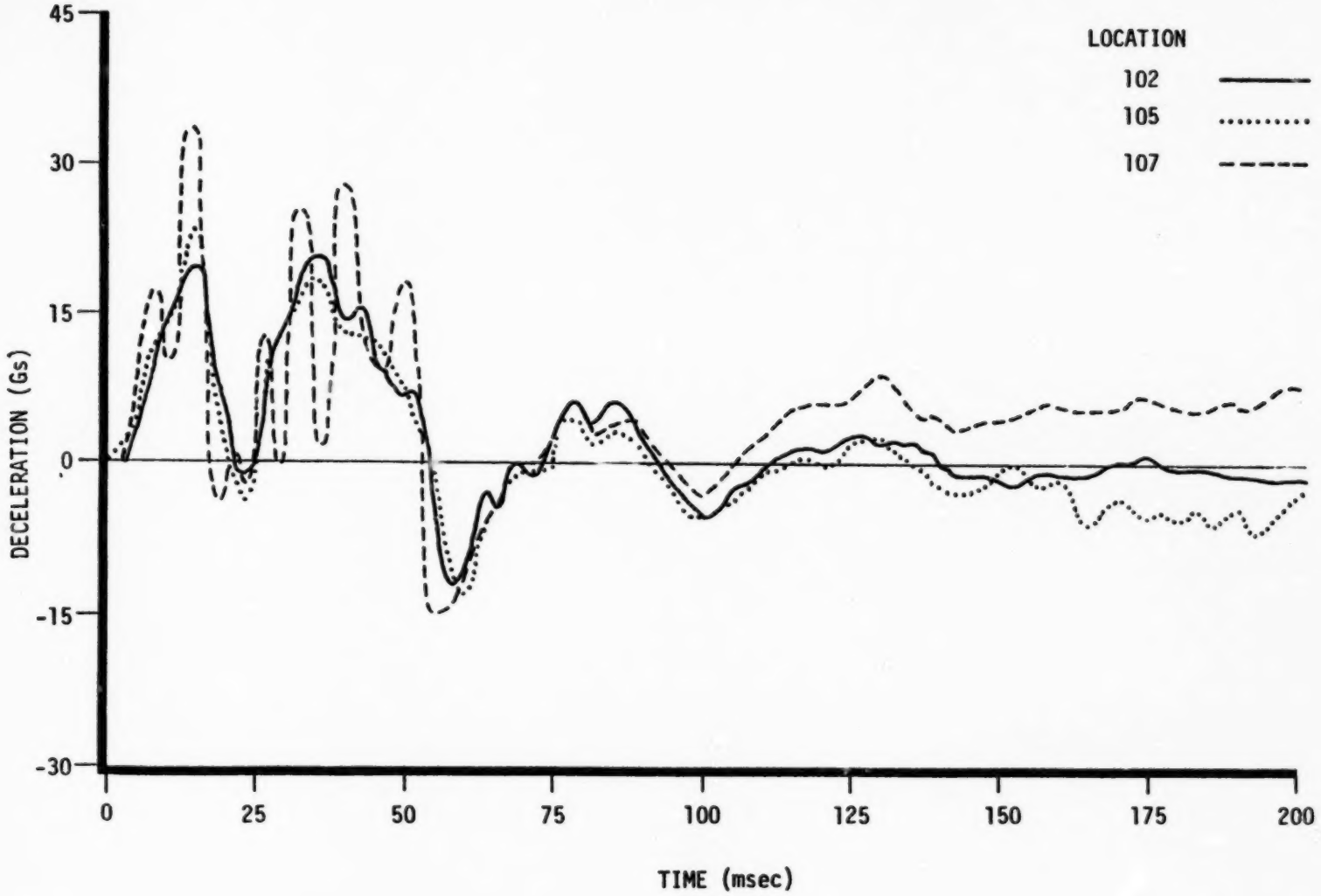


FIGURE 3-30. WAYNE BUSETTE REAR IMPACT LONGITUDINAL DECELERATIONS

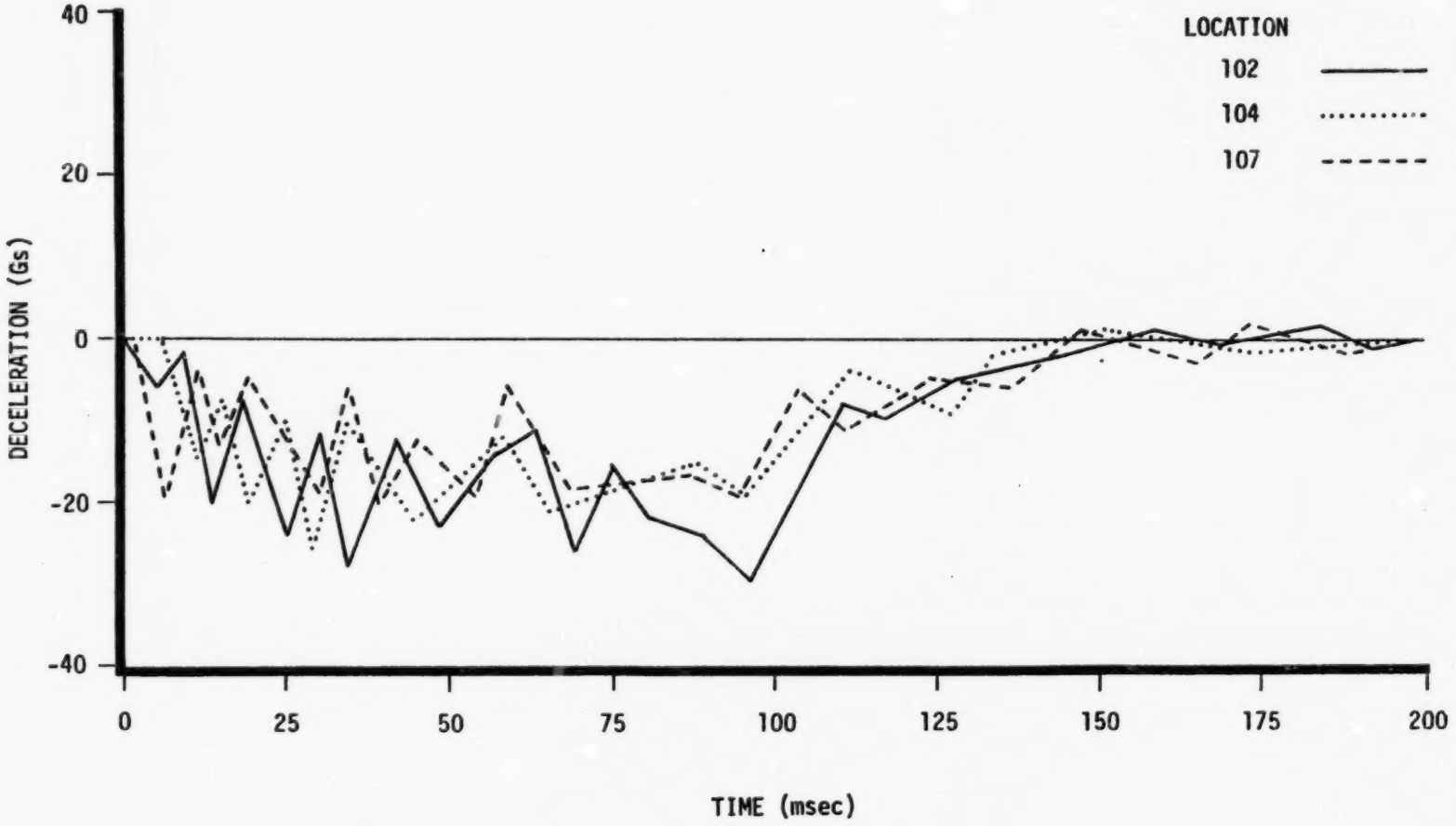
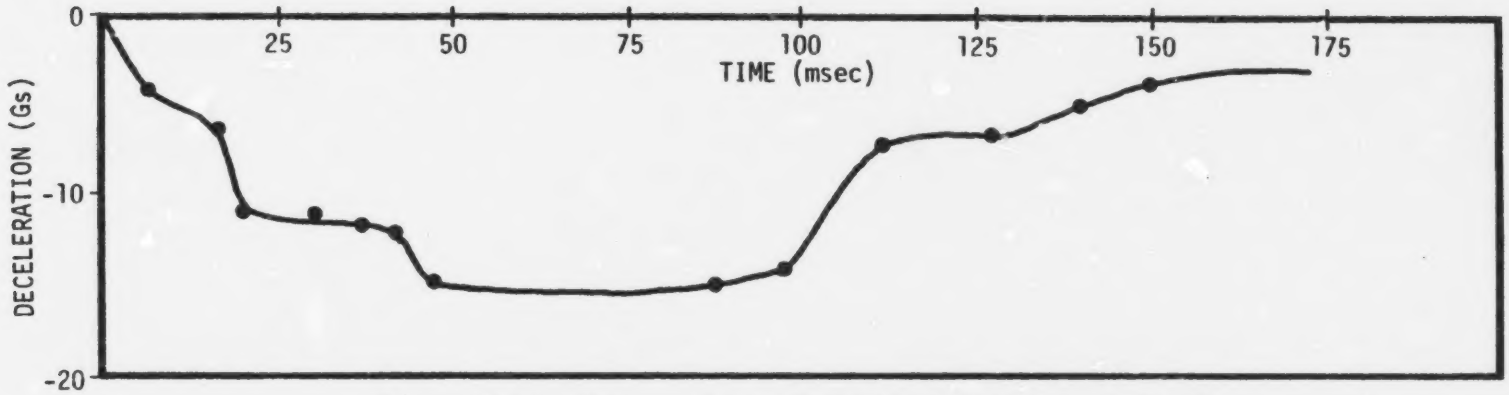
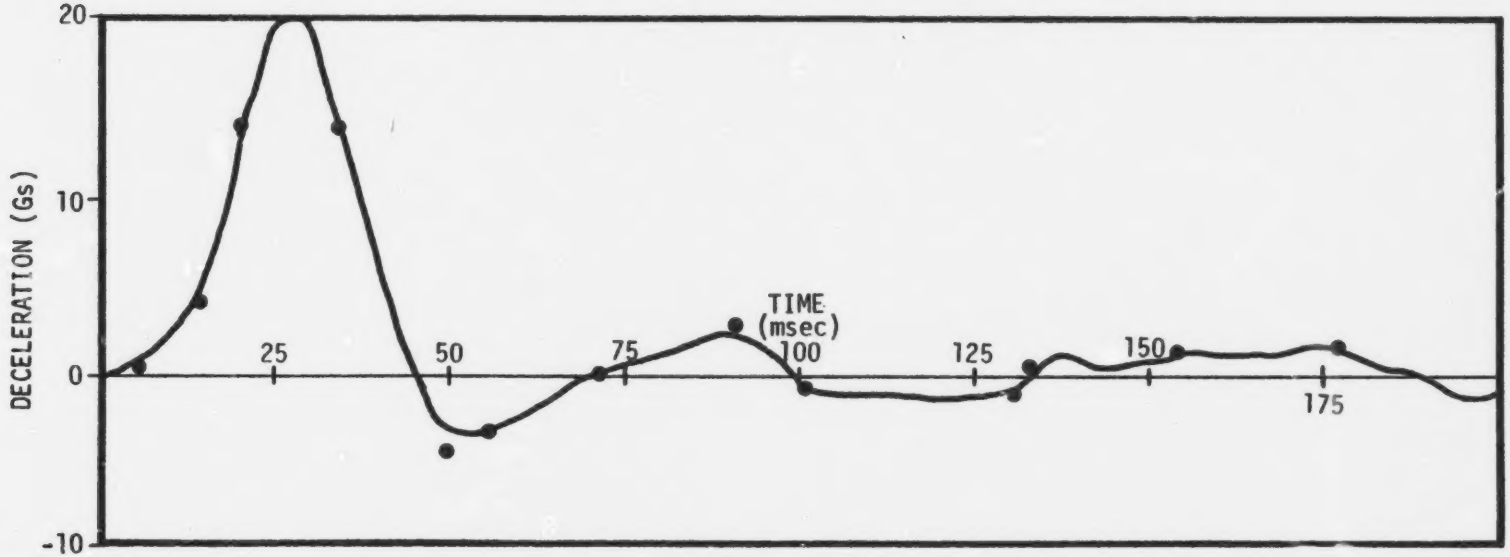


FIGURE 3-31. THOMAS MIGHTY MITE FRONT IMPACT LONGITUDINAL DECELERATIONS



Thomas Mighty Mite - Front Fixed Barrier Impact at 30 mph



Thomas Mighty Mite - Rear Moving Barrier Impact at 30 mph

FIGURE 3-32. THOMAS MIGHTY MITE COMPOSITE CRASH PULSES

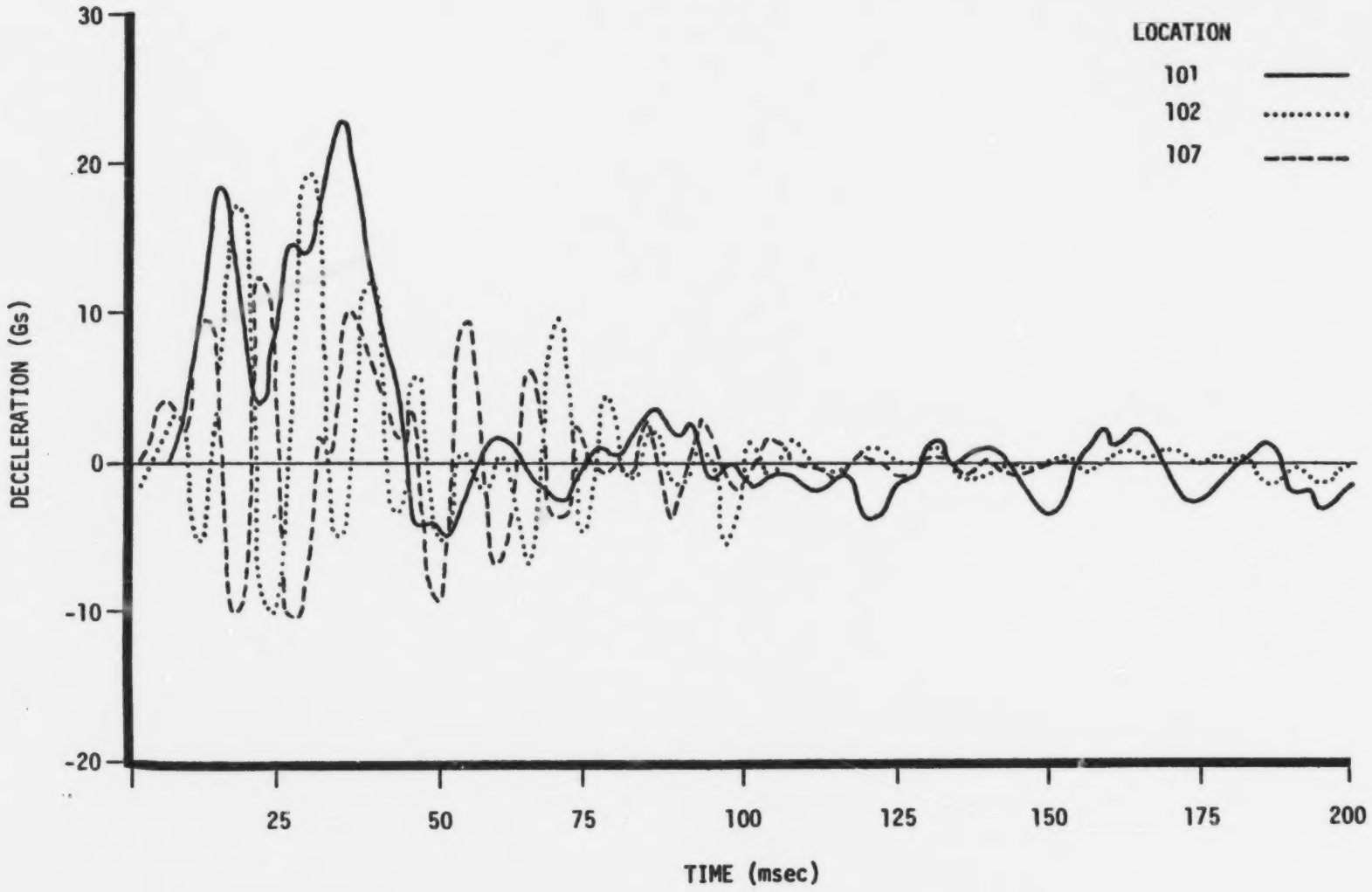


FIGURE 3-33. THOMAS MIGHTY MITE REAR IMPACT LONGITUDINAL DECELERATIONS

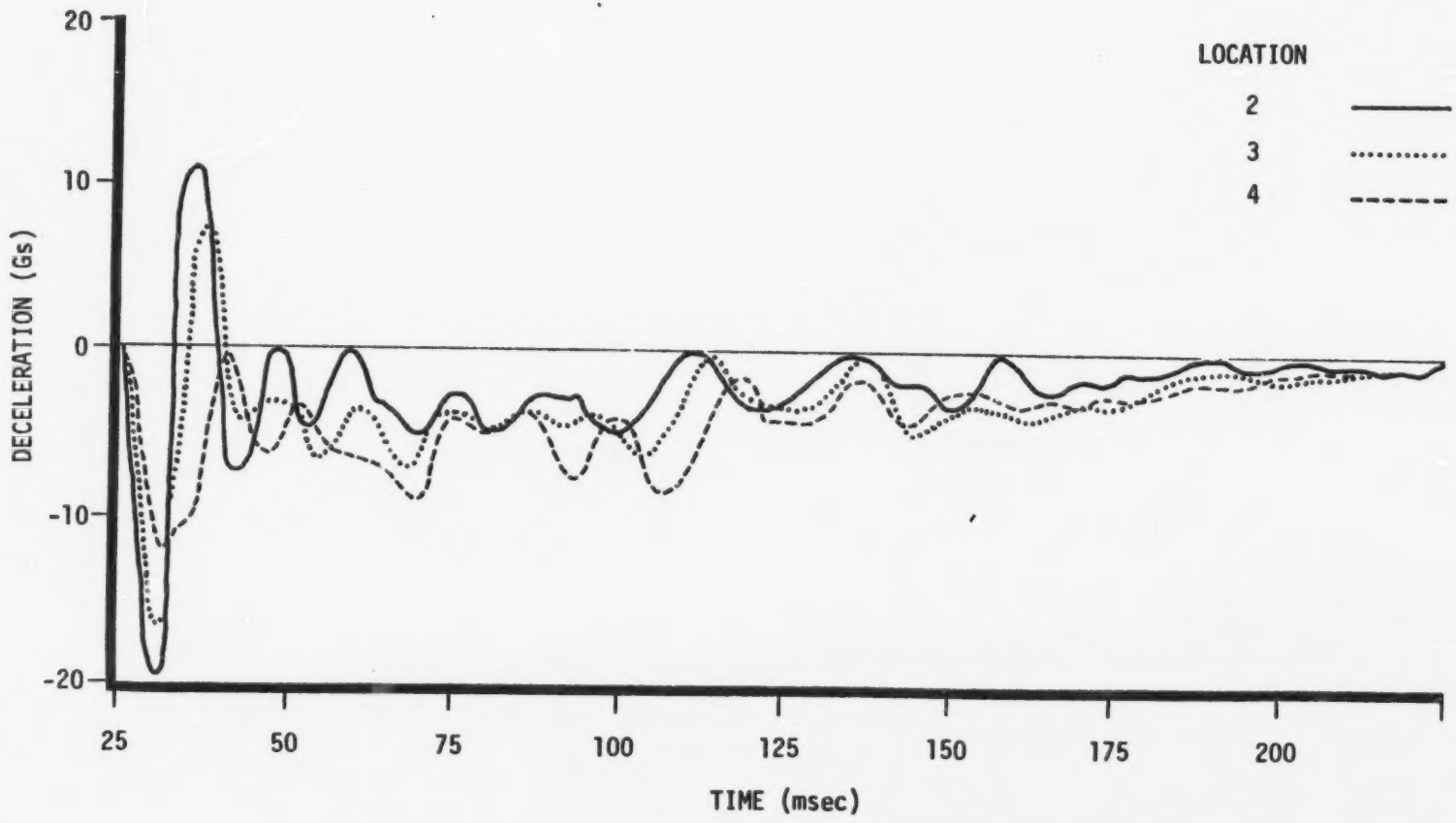
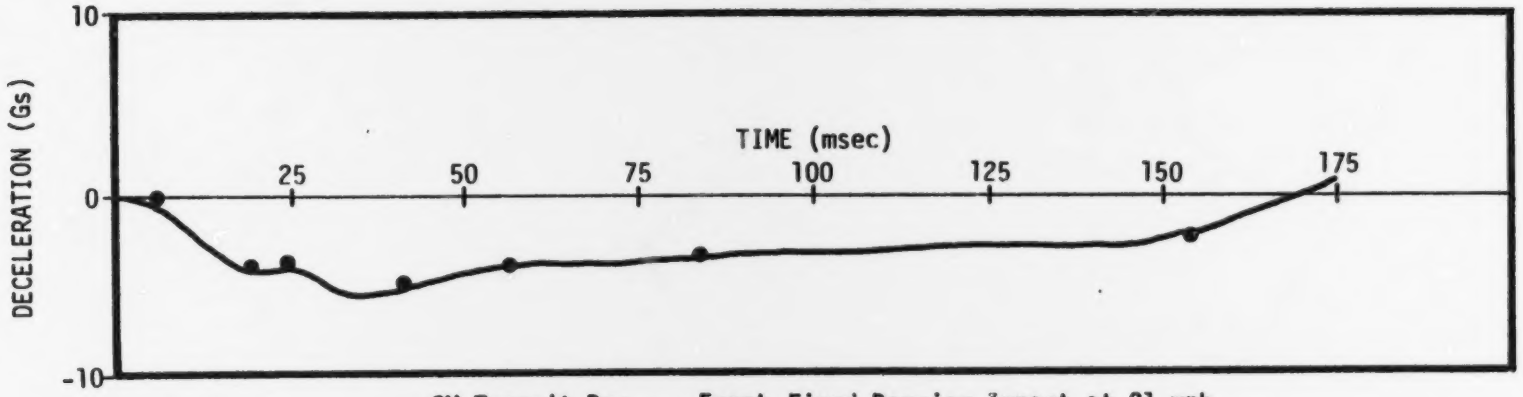
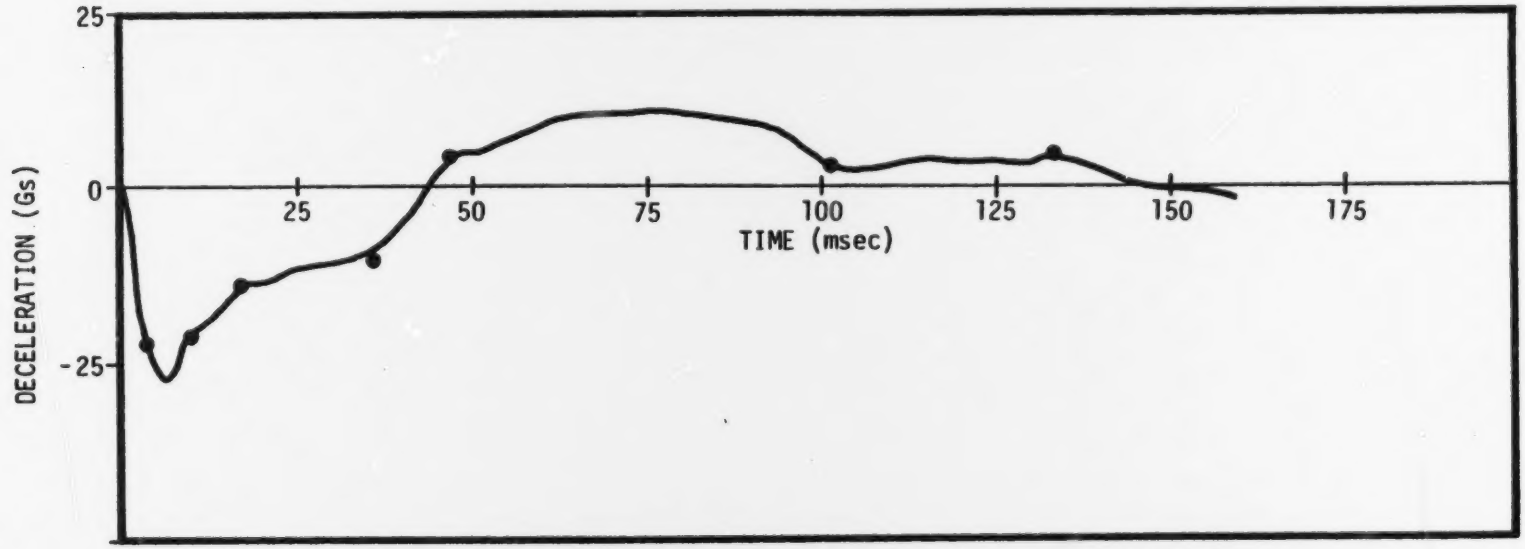


FIGURE 3-34. G.M. TRANSIT BUS FRONT IMPACT LONGITUDINAL DECELERATIONS



GM Transit Bus - Front Fixed Barrier Impact at 21 mph



GM Transit Bus - Side Moving Barrier Impact at 30 mph

FIGURE 3-35. G.M. TRANSIT BUS COMPOSITE CRASH PULSES

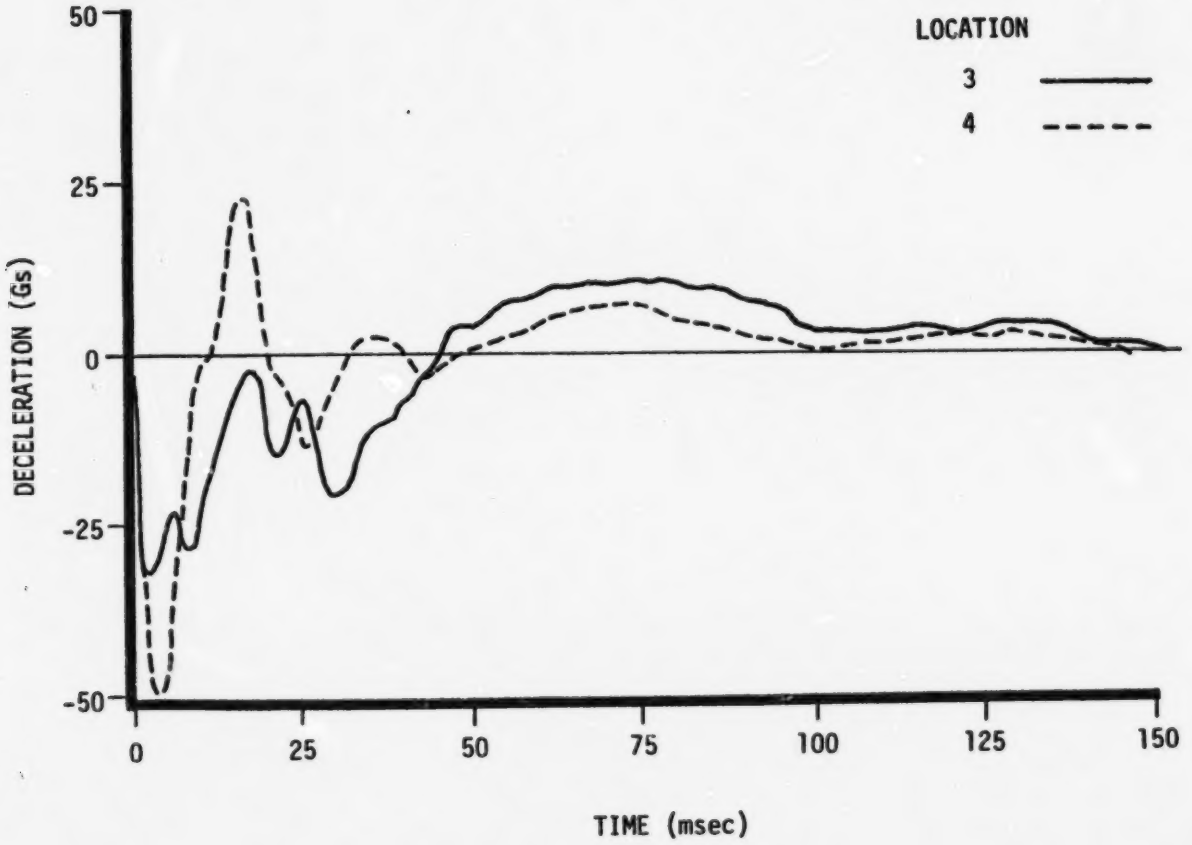


FIGURE 3-36. G.M. TRANSIT BUS SIDE IMPACT DECELERATIONS

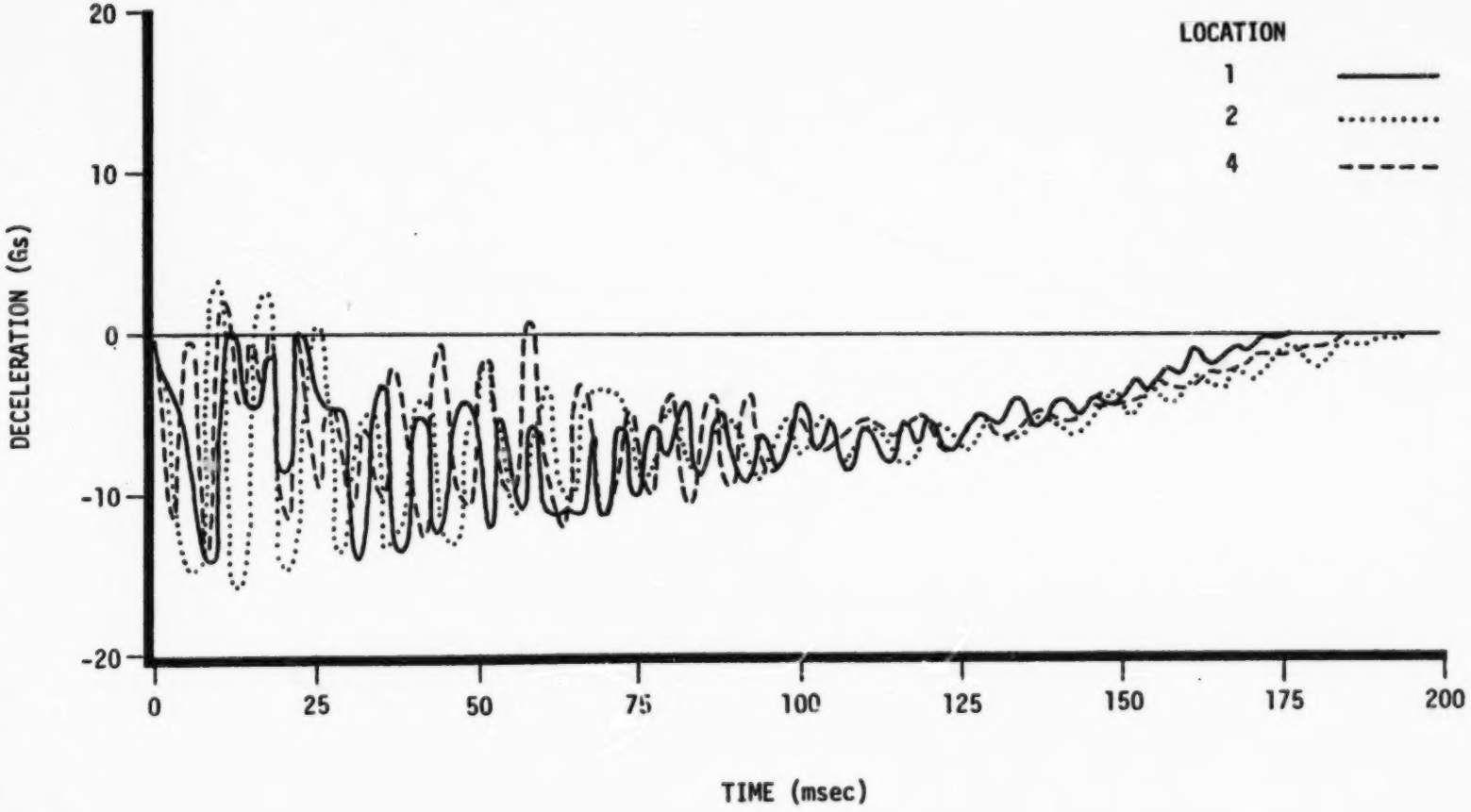
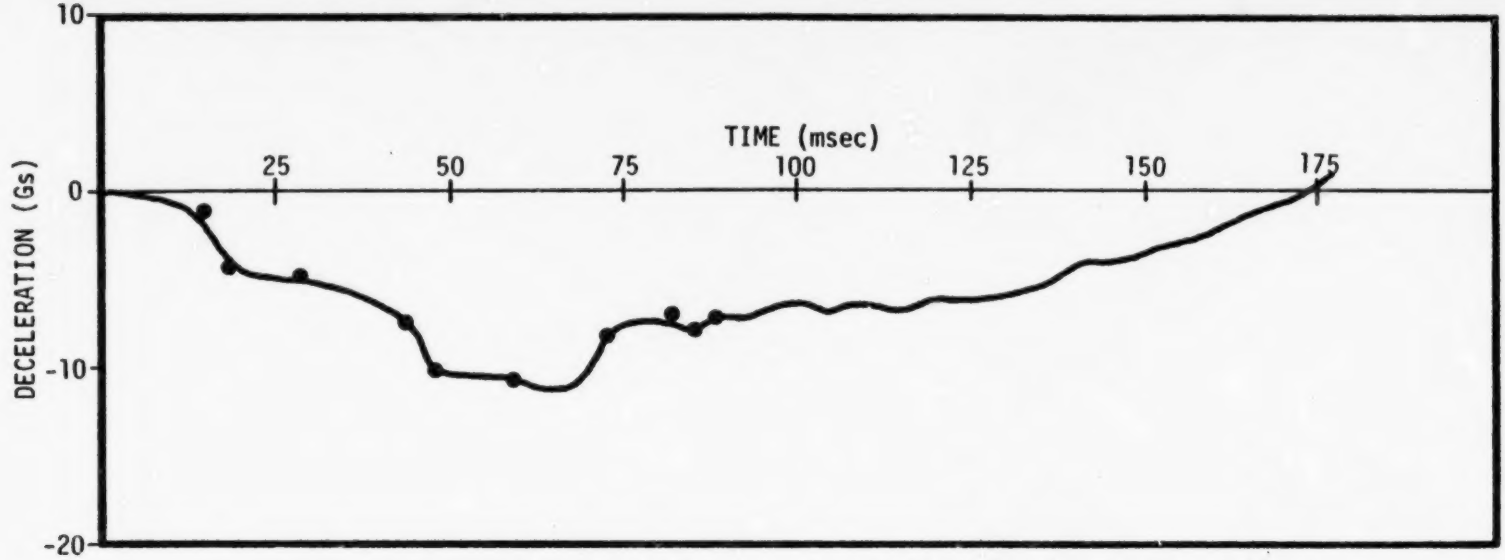
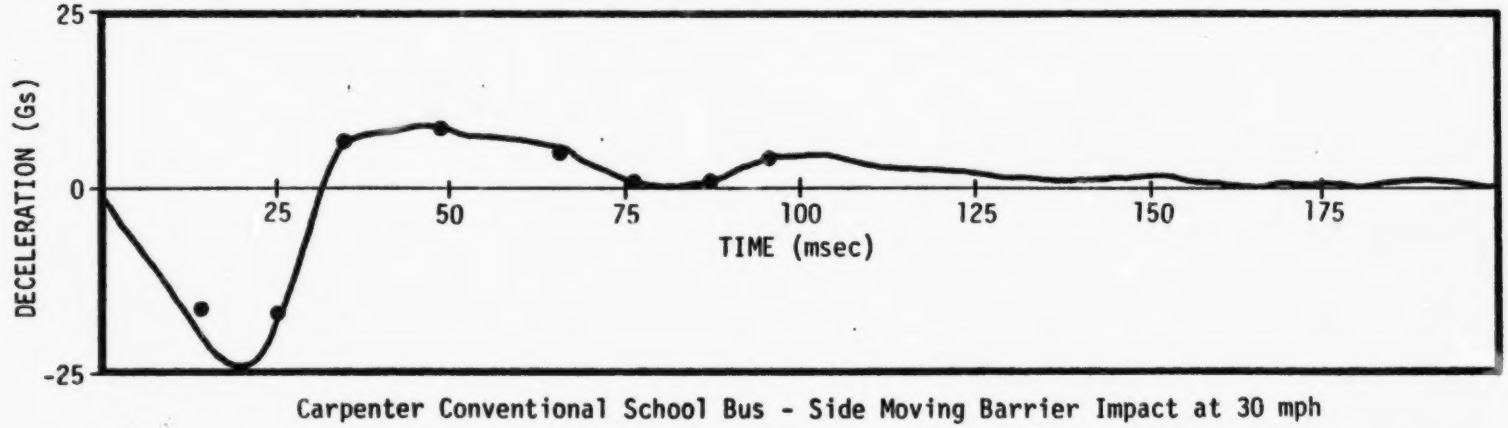


FIGURE 3-37. CARPENTER SCHOOL BUS FRONT IMPACT LONGITUDINAL DECELERATIONS



Carpenter Conventional School Bus - Front Fixed Barrier Impact at 21 mph



Carpenter Conventional School Bus - Side Moving Barrier Impact at 30 mph

FIGURE 3-38. CARPENTER SCHOOL BUS COMPOSITE CRASH PULSES

Carpenter School Bus – Side Impact (Moving barrier at 30 mph). The triangular-shaped pulse resulted because the moving barrier impacted the rear suspension of the bus. The suspension had very little give, thereby producing a steep spike. The peak value is 35 Gs at 12 msec. The total duration of the spike is 27 msec (Figures 3-38 and 3-39).

Flxible Transit Bus – Frontal Impact. This is basically a trapezoidal-shaped pulse. The rise time is 10 msec with a plateau value of 8 Gs. The time spans are 90 msec and 175 msec for the plateau and the total duration, respectively. The lack of any large spikes or drops indicates fairly even buckling. The front accelerometer exhibited a large spike, but this appears to be due to direct buckling of the mounting surface (Figures 3-40 and 3-41).

Crown Coach School Bus – Frontal Impact – First Test (Fixed barrier impact). The first time this bus was tested a triangular pulse was produced. The peak value reached is 10 Gs at 54 msec. The total duration of the pulse is 150 msec. There seems to be a uniform deformation – as indicated by the lack of significant peaks in the pulse (Figure 3-42).

Crown Coach School Bus – Frontal Impact – Second Test (Fixed barrier impact). The second test on the bus again produced a basic trapezoidal pulse. The rise time to a plateau value of 10 Gs is 13 msec. The plateau value lasts 62 msec and the total duration is 125 msec. The fluctuations are rather distinct and are attributed to the sequential buckling of the frame and body members directly in the zone of impact (Figures 3-43 and 3-44).

Crown Coach School Bus – Side Impact (Full size passenger car at 50 mph). This pulse can be characterized as trapezoidal in shape. There is an initial 5 msec rise to a plateau value of about 7 Gs. The plateau has a duration of 65 msec. The total duration is 200 msec. The sharp dropoff of the pulse at 75 msec is due to the lateral motion of the bus and bullet car together. The Crown Coach bus has a relatively high floor. This allowed the bullet car to underride the bus structure; hence, the deceleration levels are at a low value of about 7 Gs (Figures 3-44 and 3-45). A spike at about 65 msec coincides with the engagement of the bullet car's windshield with the side of the bus.

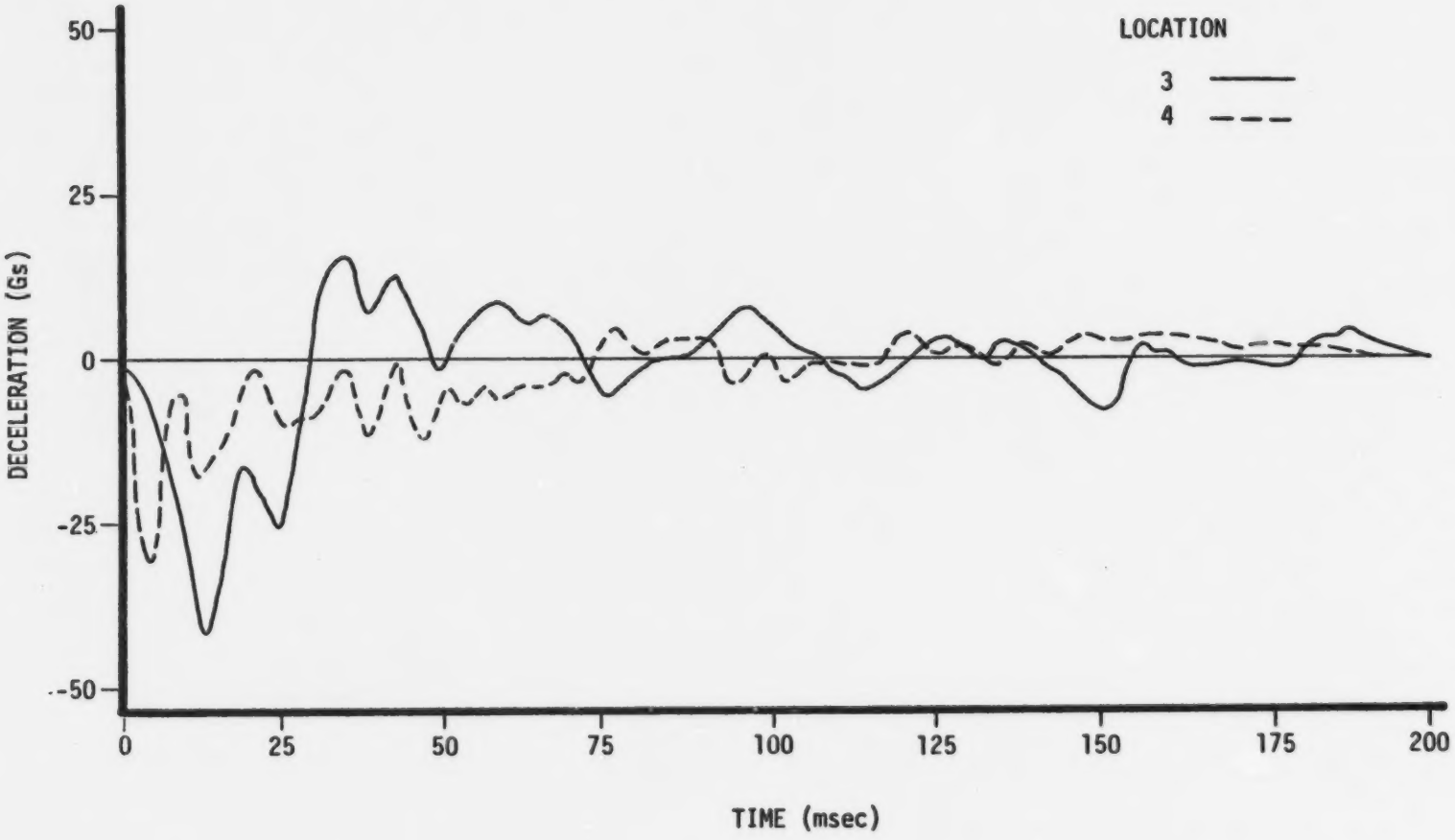


FIGURE 3-39. CARPENTER SCHOOL BUS SIDE IMPACT LATERAL DECELERATIONS

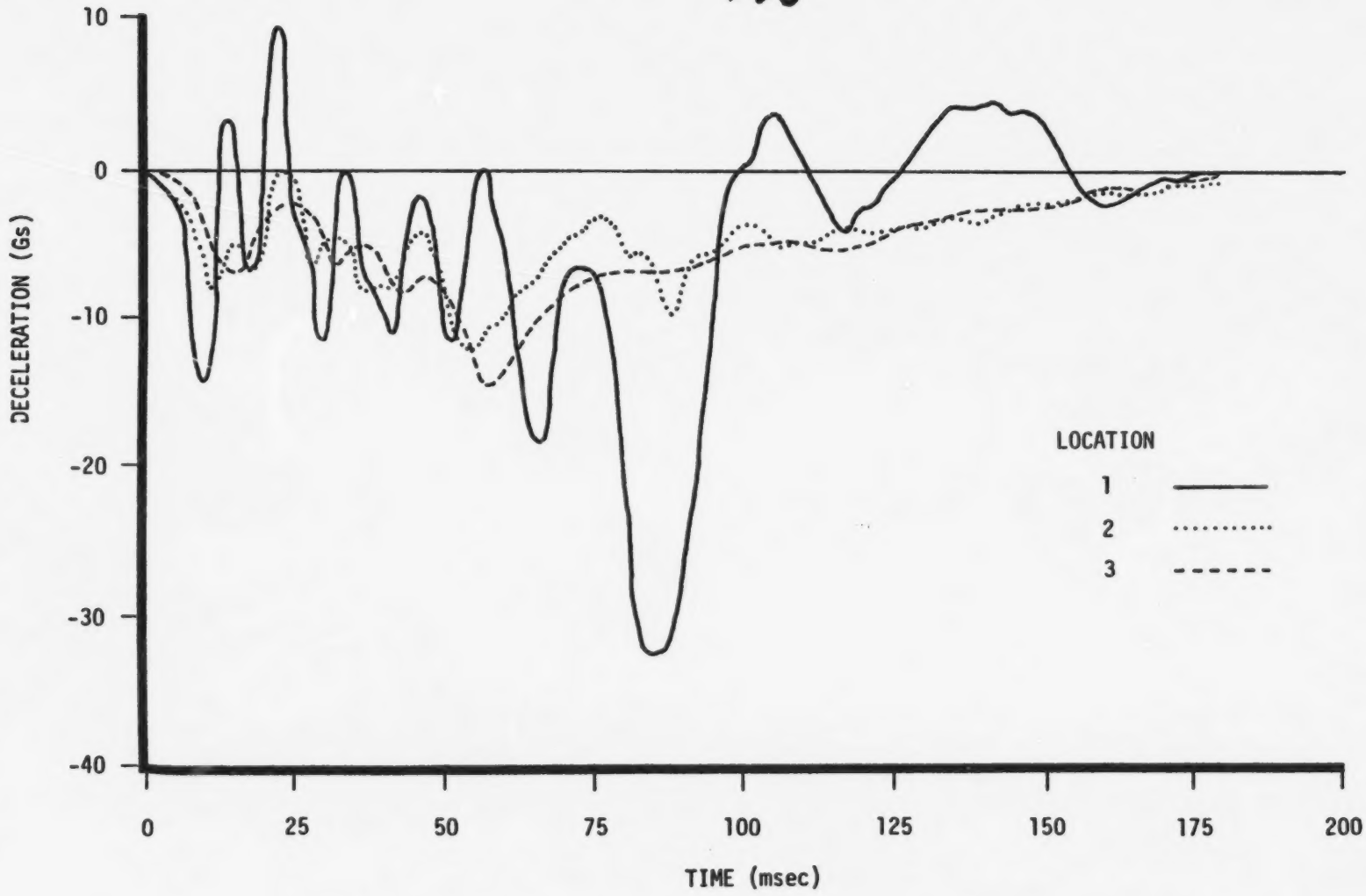


FIGURE 3-40. FLXIBLE TRANSIT BUS FRONT IMPACT LONGITUDINAL DECELERATIONS

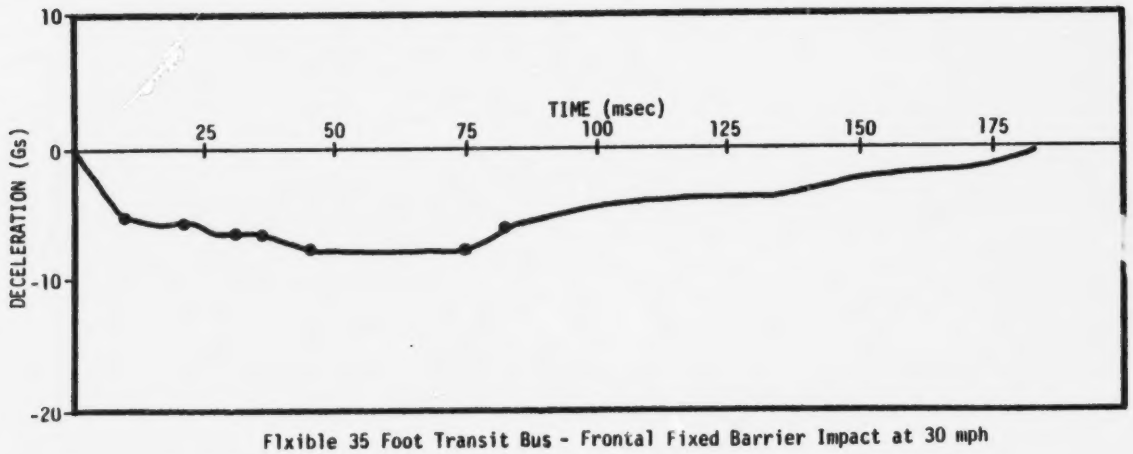


FIGURE 3-41. FLXIBLE TRANSIT BUS COMPOSITE CRASH PULSE

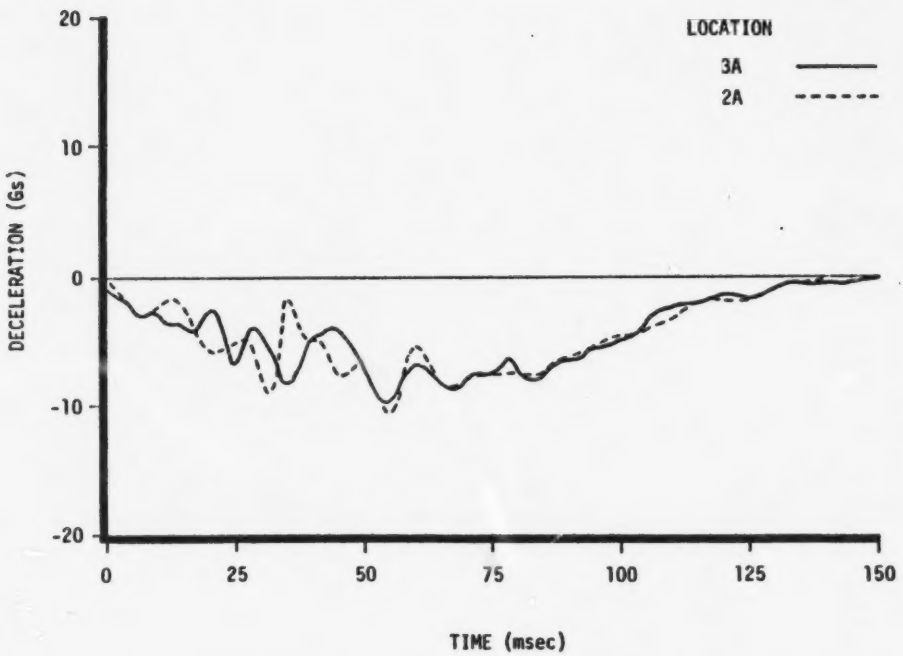


FIGURE 3-42. CROWN COACH BUS FRONT IMPACT (15.7 MPH) LONGITUDINAL DECELERATIONS

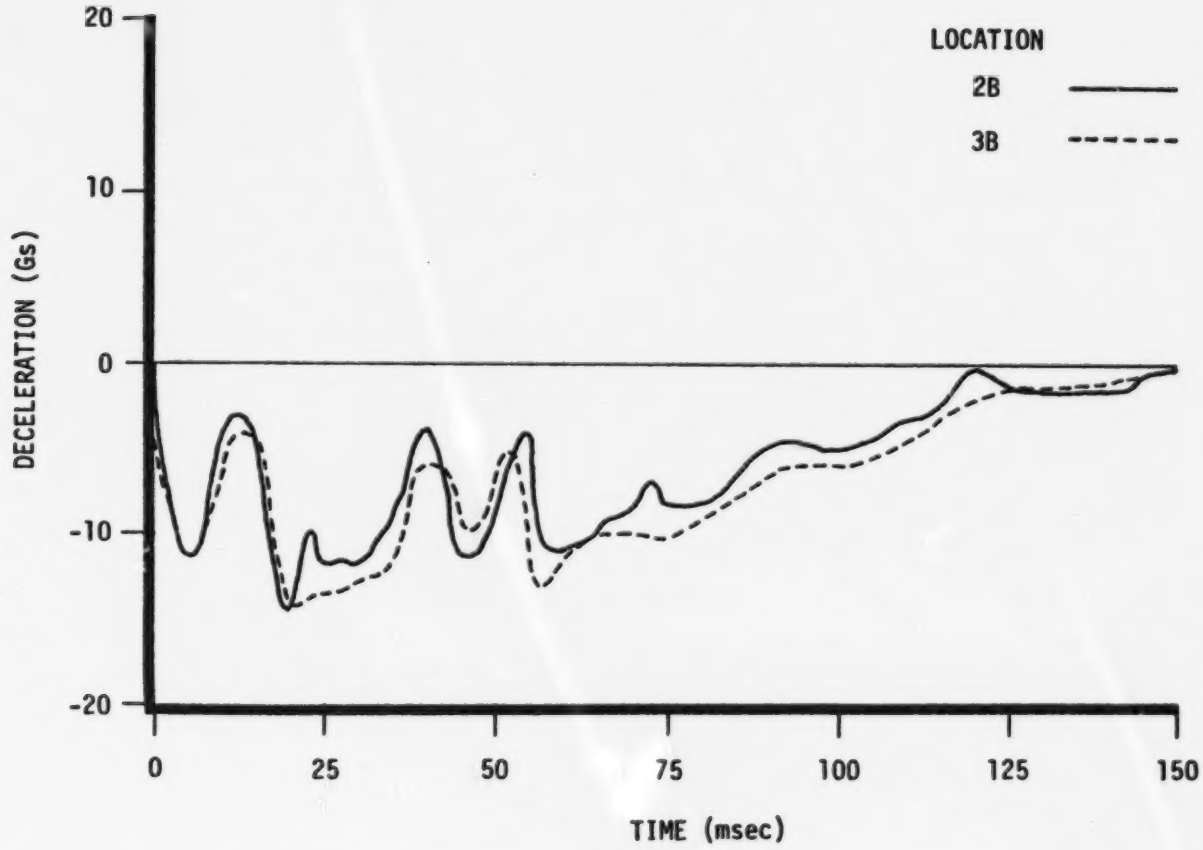
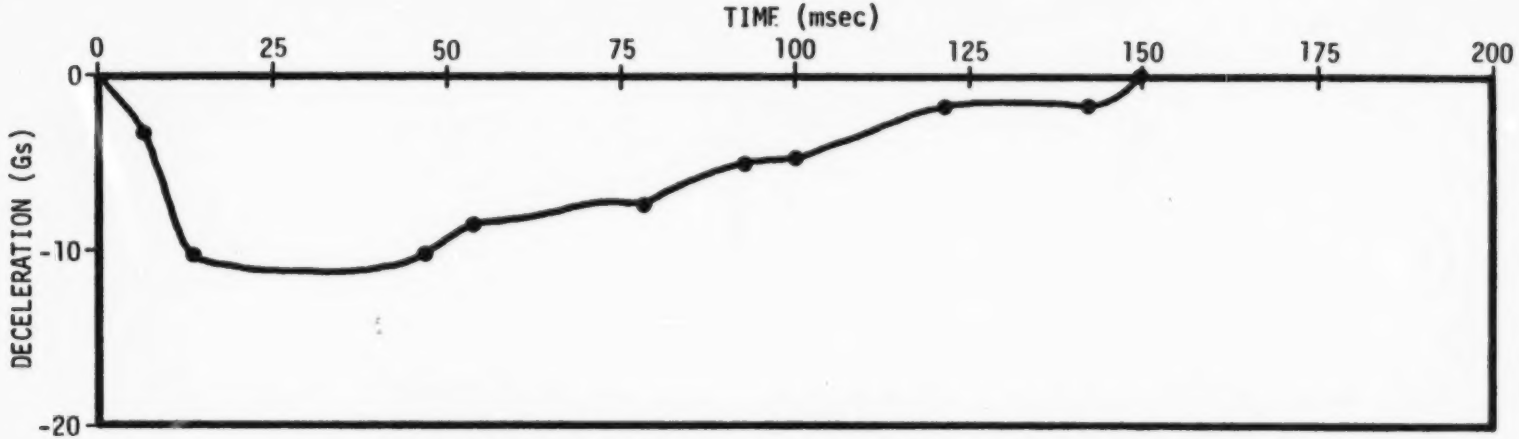
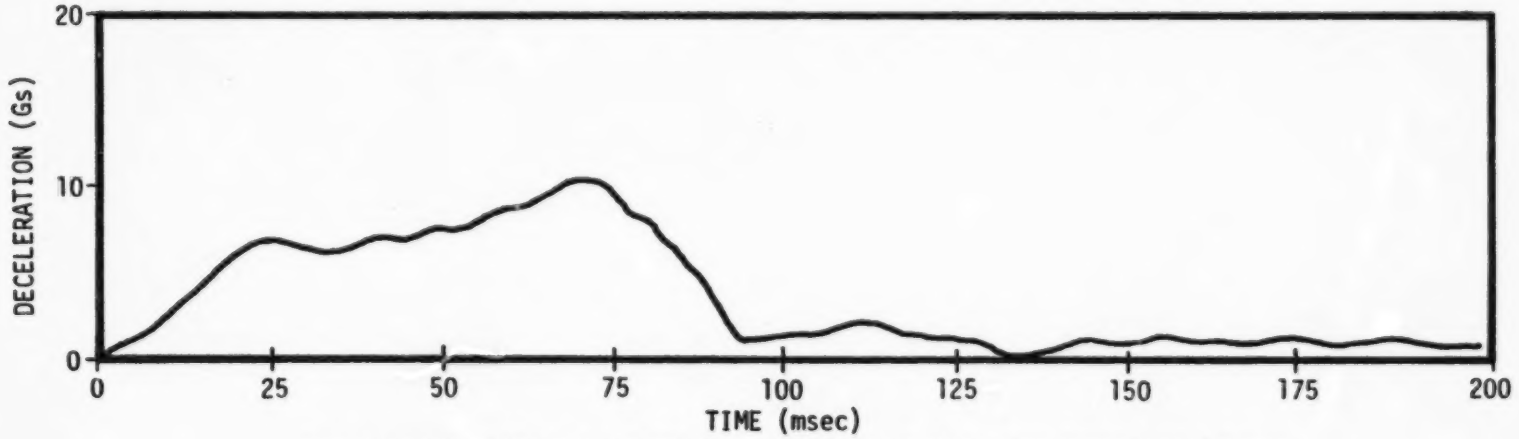


FIGURE 3-43. CROWN COACH BUS FRONT IMPACT (21.0 MPH) LONGITUDINAL DECELERATIONS



Crown Coach Unitized School Bus - Front Fixed Barrier Impact at 21 mph



Crown Coach Unitized School Bus - Side Full Size Car Impact at 50 mph

FIGURE 3-44. CROWN COACH BUS COMPOSITE CRASH PULSES

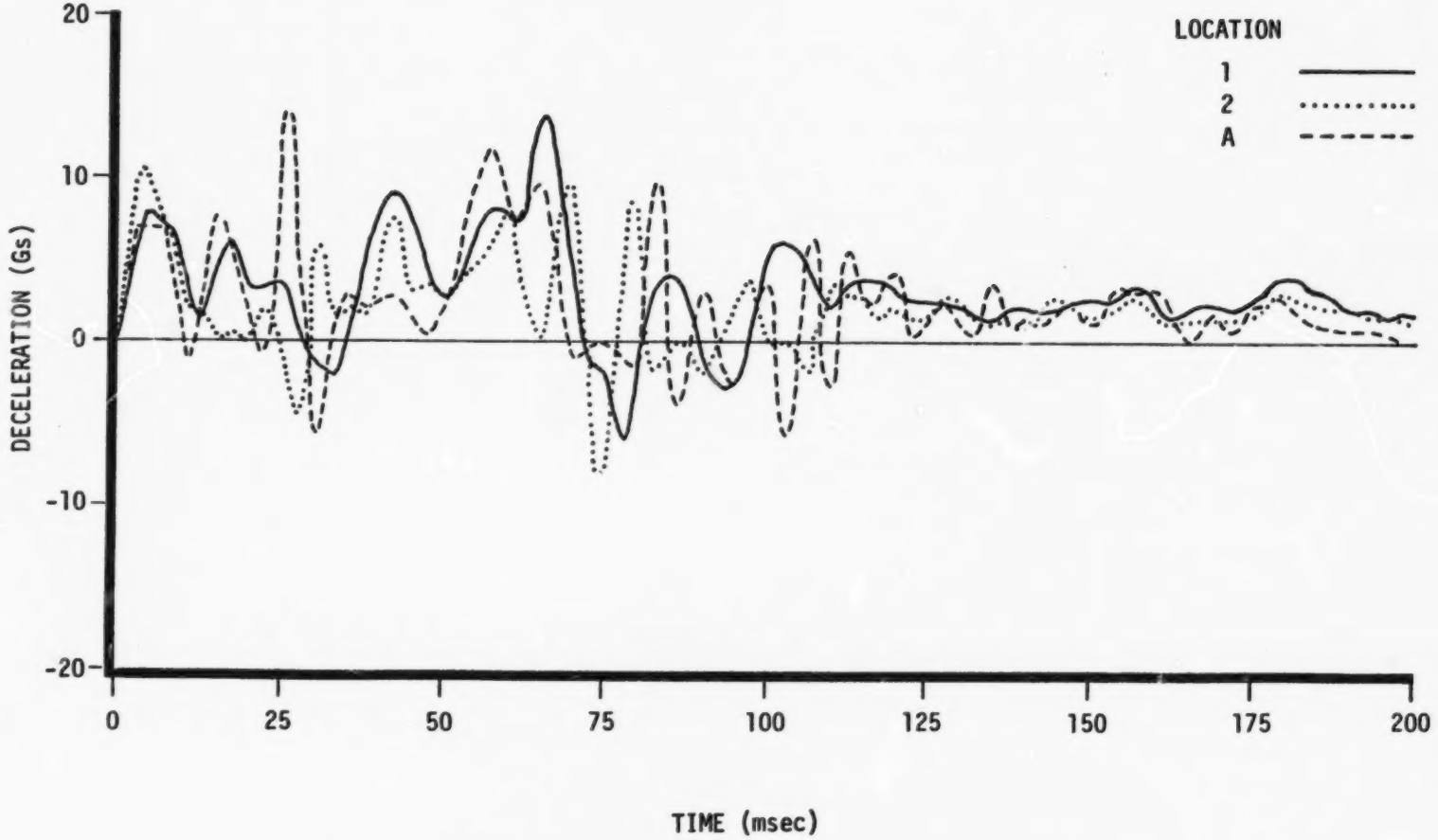


FIGURE 3-45. CROWN COACH BUS SIDE IMPACT LATERAL DECELERATIONS

Analysis and Reduction of Crash Test Pulse Data

Accelerometers positioned in different locations within a bus did not register identical pulses, but had the same general shape. The pulses are affected by both the construction of the bus and the distance from the point of impact.

It was noted that in buses with separate chassis-frame construction (such as the Carpenter, Thomas and Wayne buses), a frame mounted accelerometer had much wider fluctuation than a floor mounted one. This is due to the damping nature of the floor boards. Since the frame is stiffer, it transmits more of the high frequency vibrations than the floor boards.

Regardless of the type of construction, the pulses of the accelerometers closest to the point of impact registered more high frequency vibrations than those farther away. The accelerometer pulses were also affected by deformation of the mounting locations. This resulted in erratic spikes unrepresentative of the true crash pulse.

The Crown bus pulses depended on which side of the centerline the accelerometers were located. Those on the left exhibited greater fluctuations than those on the right. This can be attributed to the fact that the structural discontinuities, such as the door and the step well on the right side, dampened some of the impact, while the continuous stiff side wall structure on the left transmitted the deceleration forces directly and produced some high frequency vibrations.

In side impacts the differences are not as predictable since the bus is usually not symmetric about the point of impact. The pulses generally had the same basic shape with their highest magnitudes occurring nearest the point of impact. The three buses subjected to side impact tests showed similar results.

Rear impact pulses have the same characteristics as front impacts with the exception of the engine spike. All the pulses have similar sharp rises and fairly short durations.

3.2.3.3 Structural Deformations

The buses generally experienced different types of damage but there were similarities. In the frontal impacts the buses with either rear or mid engines suffered extensive damage in their driver and passenger compartments. Those with a front engine had much less interior damage. The extra space of the front engine compartment absorbs much of the impact energy, while the driver's compartment is the foremost section of the rear and mid engine buses. Table 3-6 summarizes the structural deformations of all of the buses. The following is a more detailed account of the deformations of the individual test buses.

Wayne Busette. The Wayne Busette suffered very heavy damage in the front impact. The front cab area was completely crushed, but the modified bus section showed no buckling at all. Upon impact, the bus experienced extensive pitching (the rear of the bus rising off the ground). Because of the extensive deformation of the front, both side doors to the van portion were rendered useless, while the side door on the bus section remained unchanged. The roof suffered little damage, since it did not extend to the front of the bus. The front windshield was completely shattered by the impact.

The driver's area suffered the most damage. The driver was pinned to his seat by the steering wheel and crushed door. The dashboard rose up to face level as it was pushed back into the driver. In the passenger compartment the padded stanchion bent forward under the force of the wheelchair dummy. The restraining bar on the side facing seat bent under the impact of the child and adult dummies. There was deformation of the seat back on the forward facing seat, but no major damage was noted.

The damage sustained in the rear impact was not as extensive as the front. The intrusion of the moving barrier did not directly affect the passengers inside. The rear doors were bent in at the bottom but could still be opened (though the hinges had been damaged).

In both the front and rear impacts there was no damage to the lift. The body of the busette slid forward in the front impact but hardly moved in the rear impact.

TABLE 3-6. SUMMARY OF STRUCTURAL DEFORMATION OF TEST BUSES

Test No.	Test Bus	Test Mode	Structural Deformation (inches) Static	Dynamic	Remarks
1	Wayne Busette	Fixed barrier at 30 mph, frontal	34.0	52.0	Extensive damage, front door inoperable. Body moved forward with respect to the chassis.
		Moving barrier at 30 mph, rear	7.0	12.0	Rear doors could be opened, although damaged at the bottom.
2	Thomas Mighty Mite	Fixed barrier at 30 mph, frontal	21.0	28.0	Front door inoperable. Bus body moved foward with respect to the chassis.
		Moving barrier at 30 mph, rear	5.5	7.5	Limited damage. Doors could be opened, although damaged at the bottom.
3	Flxible 35 foot transit bus	Fixed barrier at 21 mph, frontal	26.37	37.5	Front doors inoperable. The front wheel wells and area between them buckled.
4	Carpenter conventional school bus	Fixed barrier at 21 mph, frontal	21.0	34.5	Engine compartment and undercarriage crushed.
		Moving barrier at 30 mph, side	7.625	8.5	Limited damage.

TABLE 3-6. (CONT'D)

Test No.	Test Bus	Test Mode	Structural Deformation (inches) Static	Dynamic	Remarks
5	GM transit bus	Fixed barrier at 21 mph, frontal	28.4	40.0	Front doors inoperable. The front wheel wells and area between them buckled.
		Moving barrier at 30 mph, side	12.0	15.5	Door could be opened. The bus moved to the side.
6	Crown Coach unitized Construction school bus	Fixed barrier at 15.7 mph, frontal	5.9	7.0	Limited damage.
		Fixed barrier at 21 mph, frontal	25.25	30.5	Buckling of floor at driver seat anchor points. Door area damaged.
		Passenger car at 50 mph, side	-	-	Most damage was in the underfloor area. Limited damage to the side walls.
7	Flxible 40 foot transit bus	Fixed barrier at 21 mph, frontal	24.31	37.0	Damage very similar to the Flxible 35 foot bus.
8	Carpenter conventional school bus	Fixed barrier at 21 mph, frontal	20.50	28.5	Damage very similar to Test 4 above.

Thomas Mighty Mite. The exterior damage to the Thomas Mighty Mite was limited to the crush of the front end, and all of that was to the section forward of the windshield. The wheelwell was pushed into the front tire at the same time the body slid forward (about 2 to 3 inches) on the frame. The front axle was pushed rearward as it contacted the barrier. There was minimal buckling of the roof and only slight buckling at the rear of the driver's compartment. The front doors were bent but could be forced open. The front windshield popped out and flew forward over the barrier.

Inside the bus the driver struck the steering wheel, bending it downward and forward. The seat back of a forward facing seat was bent forward but returned to approximately its original position. The armrest on the side facing seat collapsed under the force of the child and adult dummies. The seat back of the seat in front of the side facing wheelchair was bent forward, touching the back of the seat in front of it. The seat mounts of the same seat were pulled out of the floor by the impact of the dummy. A wheelchair wheel caught the edge of the control unit for the hydraulic lift and pulled it off the wall of the bus. The unit had been securely attached with sheet metal screws.

The rear impact did not inflict as much damage on the bus as did the front impact. The lower portion of the rear door was bent in but could still be opened. Interior damage was minimal. The rear windows were broken by the head of the side facing wheelchair dummy. There was slight buckling of the floor near the rear door.

Transit Buses. The GM and Flxible transit buses suffered similar damage. The front windshields of these buses project forward and therefore contacted the barrier very early in the event. In both buses the windshield shattered and its frame became flush with the barrier. This allowed the driver's head to strike the barrier.

Since the doors are located at the front, they suffered substantial damage. On both buses the extensive crush completely destroyed the front entryway, so that it could not be used as an escape. The roof and the side panels also buckled and there was a large amount of deformation of the front wheelwells and the floor

area between the wheelwells. The side windows popped out as the side panels buckled.

The primary interior damage was near the front. The steering wheel and dashboard were pushed into the driver, increasing his injury level. The stanchions in the front were damaged by the buckling of the floor and the impacts of the dummies (the floor deformed throughout the front half of both buses). The seat backs of the front facing seats bent forward as they were struck from the rear by the dummies. All of the seat cushions came loose and flew through the compartment. The forward armrests were bent forward as the dummies slid against them, rendering them useless as restraints.

The damage in the side impact was less severe than that in the front. Deformation was limited to the area around the point of impact. The rear side doors remained operable even though they were directly hit. The interior damage was limited to a buckling of the floor near the door. The bus itself slid sideways 18 inches at the front and 12 inches at the rear.

Carpenter School Bus. The front of the Carpenter school bus suffered extensive damage. The front engine compartment was crushed to the point that the bumper was pushed into the tires. However, all of the crush appeared to be in the engine compartment, and there was very little damage in the passenger compartment. The door was deformed but could be forced open. The damage to the front of the passenger compartment was due primarly to the sliding of the body structure 10 inches forward on the frame.

Interior damage was minimal. The seat backs bent forward when they were struck by the dummies. The modesty panel just forward of the forward facing wheelchair was bent extensively.

The side impact caused little interior damage. There was some buckling of the floor near the point of impact, but there was little crush, because the barrier struck the rear suspension area.

Crown Coach. The Crown Coach school bus was crashed once at 15 mph and once at 21 mph. In the first test the exterior damage was not extensive. The side

panels buckled between the wheels and the bumper, and the front door was damaged, but it could still be opened by hand. Inside the bus the majority of the damage occurred in the driver's compartment; the dashboard and steering wheel were pushed back into the driver, and the front windshield shattered and fell out. The armrest on the side facing seat was bent sideways from the force of the two dummies.

The damage in the second test was much more extensive. The crush of the front end (see Table 3-6) increased so much that the front door was completely blocked off, and the wheelwell was pushed back into the tires. The front end intruded into the driver's compartment sufficiently that the driver's head directly contacted the barrier. The dashboard and steering wheel were then pushed back even further. Buckling of the floor boards near the driver allowed the mounting of the driver's seat to come loose. The armrest of the side facing seat and the seat backs of forward facing seats sustained the same damage as in the first test.

In the side impact the target car underrode the bus by 8 feet. Since the area where the car hit was empty storage, the exterior damage to the bus was very localized, extending to the outside dimensions of the target car. In the interior there was no apparent buckling.

3.2.3.4 Dummy Trajectories

In this section we describe the crash trajectories of several common types of seating positions found in school and transit buses. The wheelchair passenger dummies were restrained with seat belts to the wheelchairs, and the wheelchairs were secured to the bus. All other passenger dummies were unrestrained. Table 3-7 lists the information taken from the instrumented dummies.

The data on possible passenger excursions and impact points are established from these trajectories. This information is then used to decide where and what can be done to reduce the severity of impact. Once it is known how the side-facing passengers and wheelchair occupants react in a crash, they can be given the same level of protection that normally seated forward-facing passengers have.

For each dummy, the trajectory of the knee, chest and head reference points during the impact event are plotted. The numbers refer to time during the crash event in milliseconds.

TABLE 3-7. DUMMY INJURY MEASURES

Test No.	Test Bus	Test Mode	Dummy No.	HIC	Belt/Femur Load (pounds)	CSI	Dummy Excursion (inches)	Dummy Size
Forward Facing Seats								
1	Wayne Busette	Frontal fixed barrier at 30 mph	3	440.5		139	NDT	6C
			4	321.1	F 1375 B 1800	122.21	NDT	50M
		Rear moving barrier at 30 mph	3	21.1	NDT	10.99	NDT	6C
			4	27.7	B 58 F 75	11.34	NDT	50M
2	Thomas Mighty Mite	Frontal fixed barrier at 30 mph	1	1136.9	NDT	149.14	NDT	6C
			2	220.9	F 1000	220.34	NDT	50M
		Rear moving barrier at 30 mph	1	15.9	NDT	15.01	NDT	6C
			2	39	F 80	23.28	NDT	50M
3	Flxible 35 foot transit bus	Frontal fixed barrier at 21 mph	----------Uninstrumented----------					
4	Carpenter conventional school bus	Frontal fixed barrier at 21 mph	3	DL	DL	DL	1	6C
			4	DL	DL	DL	1.5	50M
		Side moving barrier at 30 mph	3	8.52		7.5	3	6C
			4	6.33	F 50	1.6	1.5	50M

LEGEND: F = Femur load; B = Belt load; NDT = No data taken; DL = Data lost.

TABLE 3-7 (cont'd)

Test No.	Test Bus	Test Mode	Dummy No.	HIC	Belt/Femur Load (pounds)	CSI	Dummy Excursion (inches)	Dummy Size
Forward Facing Seats (cont'd)								
5	GM transit bus	Frontal fixed barrier at 21 mph	4	169	F 400	38	7	50M
			5	70	NDT	45	11	6C
		Side moving barrier at 30 mph	1				19	50M
			5	3.7	F 40	9.5	20	50M
			6	155.2	NDT	410	10	6C
6	Crown Coach unitized SCHOOL BUS	Frontal fixed barrier at 15.7 mph	3	85	750	44	2.5	50M
			4	174		56	12	6C
		Frontal fixed barrier at 21 mph	3	162	900	160	2.5	50M
			4	445		90	13	6C
		Side full size car at 50 mph	3	5.46	80	6	9	50M
			4	21.8		2.6	4	6C
7	Flxible 40 foot transit bus	Frontal fixed barrier at 21 mph	4	95	NDT	21.2	27.25	50M
			5	13.1	75	39.4	20.75	6C
8	Carpenter conventional school bus	Frontal fixed barrier at 21 mph	3	246	NDT	NDT	11.5	6C
			4	32.5	530	NDT	.5	50M

LEGEND: F = Femur load; B = Belt load; NDT = No data taken; DL = Data lost.

TABLE 3-7 (cont'd)

Test No.	Test Bus	Test Mode	Dummy No.	HIC	Belt/Femur Load (pounds)	CSI	Dummy Excursion (inches)	Dummy Size
Side Facing Seats								
1	Wayne Busette	Frontal fixed barrier at 30 mph	5	321.9	NDT	147.77	NDT	6C
			6	325.2	B 2450	137.78	NDT	50M
		Rear moving barrier at 30 mph	5	29.8	NDT	16.2	NDT	6C
			6	36.8	B 1400	29.13	NDT	50M
2	Thomas Mighty Mite	Frontal fixed barrier at 30 mph	3	1531.4	NDT	318.34	NDT	6C
			4	166.2	F 200	136.64	NDT	50M
		Rear moving barrier at 30 mph	3	12	NDT	3.17	NDT	6C
			4	37.8	F 100	71.64	NDT	50M
3	Flxible 35 foot transit bus	Frontal fixed barrier at 21 mph	----------Uninstrumented----------					
4	Carpenter conventional school bus	Frontal fixed barrier at 21 mph	5	DL	DL	DL	37	6C
			6	DL	DL	DL	7	50M
		Side moving barrier at 30 mph	5	45.25		40	14.5	6C
			6	16.72	F 240	2	9.5	50M

LEGEND: F = Femur load; B = Belt load; NDT = No data taken; DL = Data lost.

TABLE 3-7 (cont'd)

Test No.	Test Bus	Test Mode	Dummy No.	HIC	Belt/Femur Load (pounds)	CSI	Dummy Excursion (inches)	Dummy Size
Side Facing Seats (cont'd)								
5	GM transit bus	Frontal fixed barrier at 21 mph	2	712	NDT	95	4	95M
			7	200	F 120	68	5	50M
		Side moving barrier at 30 mph	3	3.1	NDT	1.6	9.5	95M
			4	7.9	F 100	2.4	23.5	50M
6	Crown Coach unitized bus	Frontal fixed barrier at 15.7 mph	5	17	F 50	4	40.75	50M
			6	992		25	10.25	6C
		Frontal fixed barrier at 21 mph	5	77	F 350	85	32.25	50M
			6	1983		88	17.75	6C
		Side full size car at 50 mph	5	0.631	F 44	0.72	9	50M
			6	0.451		1	31.75	6C
7	Flxible 40 foot transit bus	Frontal fixed barrier at 21 mph	2	56.7	B 862	44.4	1.5	95M
			7	470	B 1500	54.2	8	50M
8	Carpenter conventional school bus	Frontal fixed barrier at 21 mph	5	100.9	NDT	NDT	4.5	6C
			6	87	F 300	NDT	77.25	50M

LEGEND: F = Femur load; B = Belt load; NDT = No data taken; DL = Data lost.

TABLE 3-7 (cont'd)

Test No.	Test Bus	Test Mode	Dummy No.	HIC	Belt/Femur Load (pounds)	CSI	Dummy Excursion (inches)	Dummy Size
Wheelchair No. 1 (cont'd)								
1	Wayne Busette	Frontal fixed barrier at 30 mph	1	811.8	B 1175	126.12	NDT	50M
		Rear moving barrier at 30 mph	1	27.8	B 600	3.55	NDT	50M
2	Thomas Mighty Mite	Frontal fixed barrier at 30 mph	5	121.2	B 1500	137.44	NDT	50M
		Rear moving barrier at 30 mph	5	259.2	B 320	14.5	NDT	50M
3	Flxible 35 foot transit bus	Frontal fixed barrier at 21 mph	1	374	150	52	NDT	50M
4	Carpenter conventional school bus	Frontal fixed barrier at 21 mph	2	DL	DL	DL	3	50M
		Side moving barrier at 30 mph	2	2.91	B 340	190	1	50M

LEGEND: F = Femur load; B = Belt load; NDT = No data taken; DL = Data lost.

TABLE 3-7 (cont'd)

Test No.	Test Bus	Test Mode	Dummy No.	HIC	Belt/Femur Load (pounds)	CSI	Dummy Excursion (inches)	Dummy Size
Wheelchair No. 1 (cont'd)								
5	GM Transit Bus	Frontal fixed barrier at 21 mph	3	218	B 720	17	0.5	50M
		Side moving barrier at 30 mph	2	5.1	B 980	2.9	6	50M
6	Crown Coach unitized school bus	Frontal fixed barrier at 15.7 mph	2	DL	B 310	DL	7.5	50M
		Frontal fixed barrier at 21 mph	2	122	B 430	83	10.25	50M
		Side full size car at 50 mph	2	64.1	NDT	6.6	9.5	50M
7	Flxible 40 foot transit bus	Frontal fixed barrier at 21 mph	3	114.1	490	41.1	2	50M
8	Carpenter conventional school bus	Frontal fixed	2	70	B 890	NDT	6	50M

LEGEND: F = Femur load; B = Belt load; NDT = No data taken; DL = Data lost.

TABLE 3-7 (cont'd)

Test No.	Test Bus	Test Mode	Dummy No.	HIC	Belt/Femur Load (pounds)	CSI	Dummy Excursion (inches)	Dummy Size
Wheelchair No. 2								
1	Wayne Busette	Frontal fixed barrier at 30 mph	2	186.3	F 200	110.93	NDT	50M
		Rear moving barrier at 30 mph	2	49.8	F 110	4.62	NDT	50M
2	Thomas Mighty Mite	Frontal fixed barrier at 30 mph	6	268.8	B 2300	58.53	NDT	50M
		Rear moving barrier at 30 mph	6	353.8	B 100	127.56	NDT	50M
3	Flxible 35 foot transit bus	Frontal fixed barrier at 21 mph	----------Uninstrumented----------					
4	Carpenter conventional SCHOOL BUS	Frontal fixed barrier at 21 mph	7	DL	DL	DL	65.5	50M
		Side moving barrier at 30 mph	7	67.86	B 700	17	26.5	50M

LEGEND: F = Femur load; B = Belt load; NDT = No data taken; DL = Data lost.

TABLE 3-7 (cont'd)

Test No.	Test Bus	Test Mode	Dummy No.	HIC	Belt/Femur Load (pounds)	CSI	Dummy Excursion (inches)	Dummy Size
Wheelchair No. 2 (cont'd)								
5	GM transit bus	Frontal fixed barrier at 21 mph	6	102	B 1000	26	2.5	50M
		Side moving barrier at 30 mph	7	9.8	B 800	7.2	2.5	50M
6	Crown Coach unitized SCHOOL BUS	Frontal fixed barrier at 15.7 mph	7	DL	B 1600	DL	11.25	50M
		Frontal fixed barrier at 21 mph	7	342	B 1760	160	0	50M
		Side full size car at 50 mph	7	140	B 310	DL	4	50M
7	Flxible 40 foot transit bus	Frontal fixed barrier at 21 mph	6	54.9	NDT	31.1	9	50M
8	Carpenter conventional school bus	Frontal fixed	7	B	1000	NDT	49.5	50M

LEGEND: F = Femur load; B = Belt load; NDT = No data taken; DL = Data lost.

TABLE 3-7 (cont'd)

Test No.	Test Bus	Test Mode	Dummy No.	HIC	Belt/Femur Load (pounds)	CSI	Dummy Excursion (inches)	Dummy Size
Driver								
1	Wayne Busette	Frontal fixed barrier at 30 mph	D	-------Uninstrumented-------			NDT	50M
		Rear moving barrier at 30 mph	D	-------Uninstrumented-------			NDT	50M
2	Thomas Mighty Mite	Frontal fixed barrier at 30 mph	D	-------Uninstrumented-------			NDT	50M
		Rear moving barrier at 30 mph	D	-------Uninstrumented-------			NDT	50M
3	Flxible 35 foot transit bus	Frontal fixed barrier at 21 mph	-	-------Uninstrumented-------			1.5	50M
4	Carpenter conventional school bus	Frontal fixed barrier at 21 mph	1	DL	DL	DL	7	50M
		Side moving barrier at 30 mph	1	1.17	B 40	0.75	1.5	50M

LEGEND: F = Femur load; B = Belt load; NDT = No data taken; DL = Data lost.

TABLE 3-7 (cont'd)

Test No.	Test Bus	Test Mode	Dummy No.	HIC	Belt/Femur Load (pounds)	CSI	Dummy Excursion (inches)	Dummy Size
Driver (cont'd)								
5	GM transit bus	Frontal fixed barrier at 21 mph	1	8130	B 100	280	1	50M
		Side moving barrier at 30 mph	-	----------No Driver----------				50M
6	Crown Coach unitized school bus	Frontal fixed barrier at 15.7 mph	1	149	B 400	32	1	50M
		Frontal fixed barrier at 21 mph	1	2473	B 500	140	9.75	50M
		Side full size car at 50 mph	1	----------Uninstrumented----------			25.75	50M
7	Flxible 40 foot transit bus	Frontal fixed barrier at 21 mph	1	5646	B 550	153.7	9	50M
8	Carpenter conventional school bus	Frontal fixed	1	238.8	B 720	NDT	4	50M

LEGEND: F = Femur load; B = Belt load; NDT = No data taken; DL = Data lost.

Forward Facing Seats

Trajectory 1 – Forward Facing 50th Percentile Adult Male Dummy in a Large School Bus. A 50th percentile dummy is sitting in a standard forward facing seat (Figure 3-46). There is another forward facing seat directly in front of the dummy. At approximately 200 msec after impact the dummy's knees hit the back of the seat in front of him, causing him to pitch forward. By 225 msec, the dummy's head and chest have struck the seat back, bending it forward. The dummy has reached his peak forward motion at 250 msec and has begun to rebound backward and upward. At 750 msec the dummy falls down onto the (forward) seat back before sliding back into nearly his original position.

Trajectory 2 – Forward Facing 50th Percentile Adult Male Dummy in a Small School Bus. The 50th percentile male dummy is sitting in a standard forward facing seat in a small school bus (Figure 3-47). The dummy begins to move at the moment of impact. At 25 msec his knees have contacted the seat back in front of him. By 72 msec the forward motion of his knees has stopped. At that time the dummy's face first strikes the seat back; his head then continues over the seat and forward. The dummy's hip follows his head and travels over the top of the seat. By 225 msec all except his knees are in front of the forward seat.

Trajectory 3 – Forward Facing 50th Percentile Adult Male Dummy in a Transit Bus. For the first 84 msec the dummy is sliding forward on the seat (Figure 3-48). By 120 msec his knees have contacted the back of the seat in front of him. It is not until 188 msec that his head strikes the top of the seat back; it then continues forward until 248 msec before moving upward. His chest contacts the seat back at about the same time his head does. The seat back bends forward during the impact. The dummy's body rises out of the seat and then resettles back into the seat as the final position.

Side Facing Seats

Trajectory 4 – Side Facing 6-Year-Old Child Dummy Unrestrained in a Large School Bus. The dummy representing a 6-year-old is occupying a side facing seat in a large school bus (Figure 3-49). At initial impact the dummy slides toward

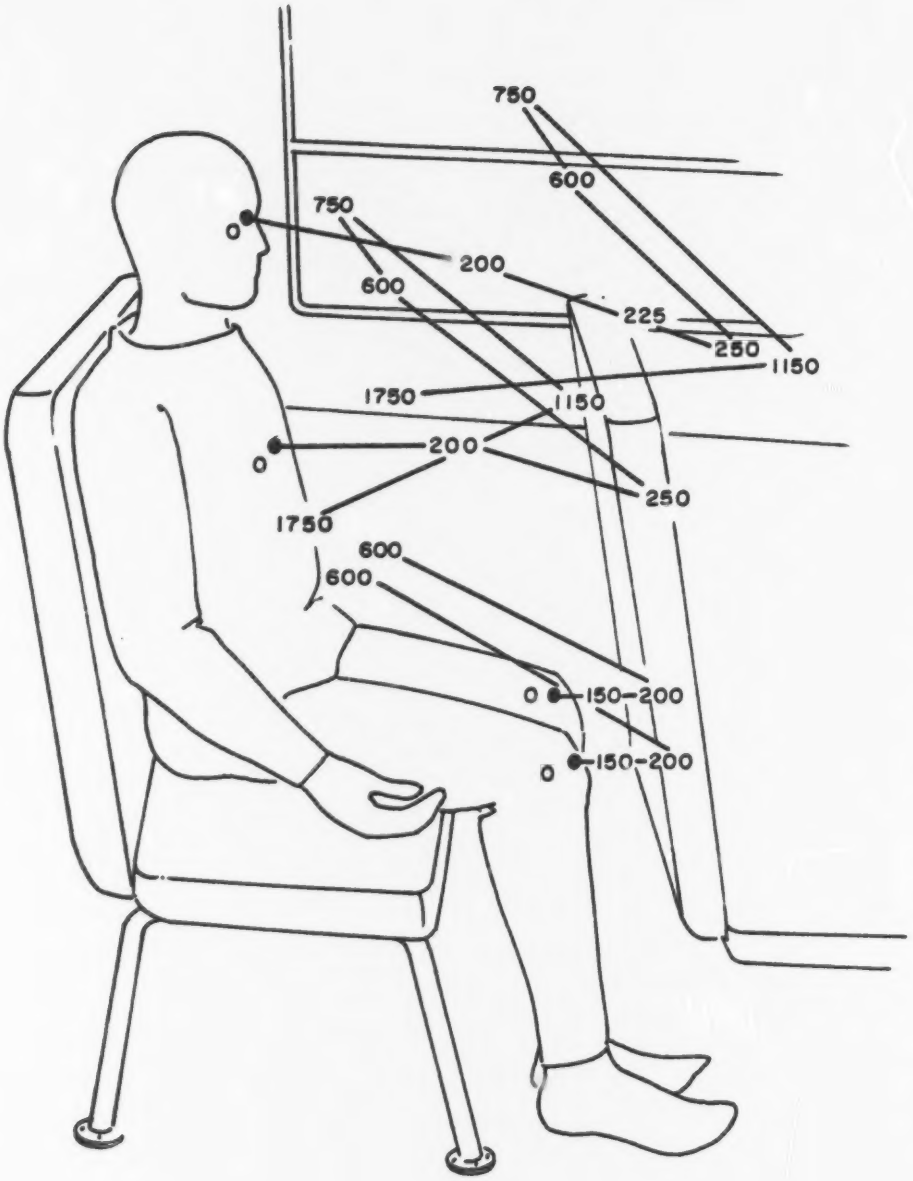


FIGURE 3-46. FORWARD FACING 50TH PERCENTILE MALE IN A LARGE SCHOOL BUS

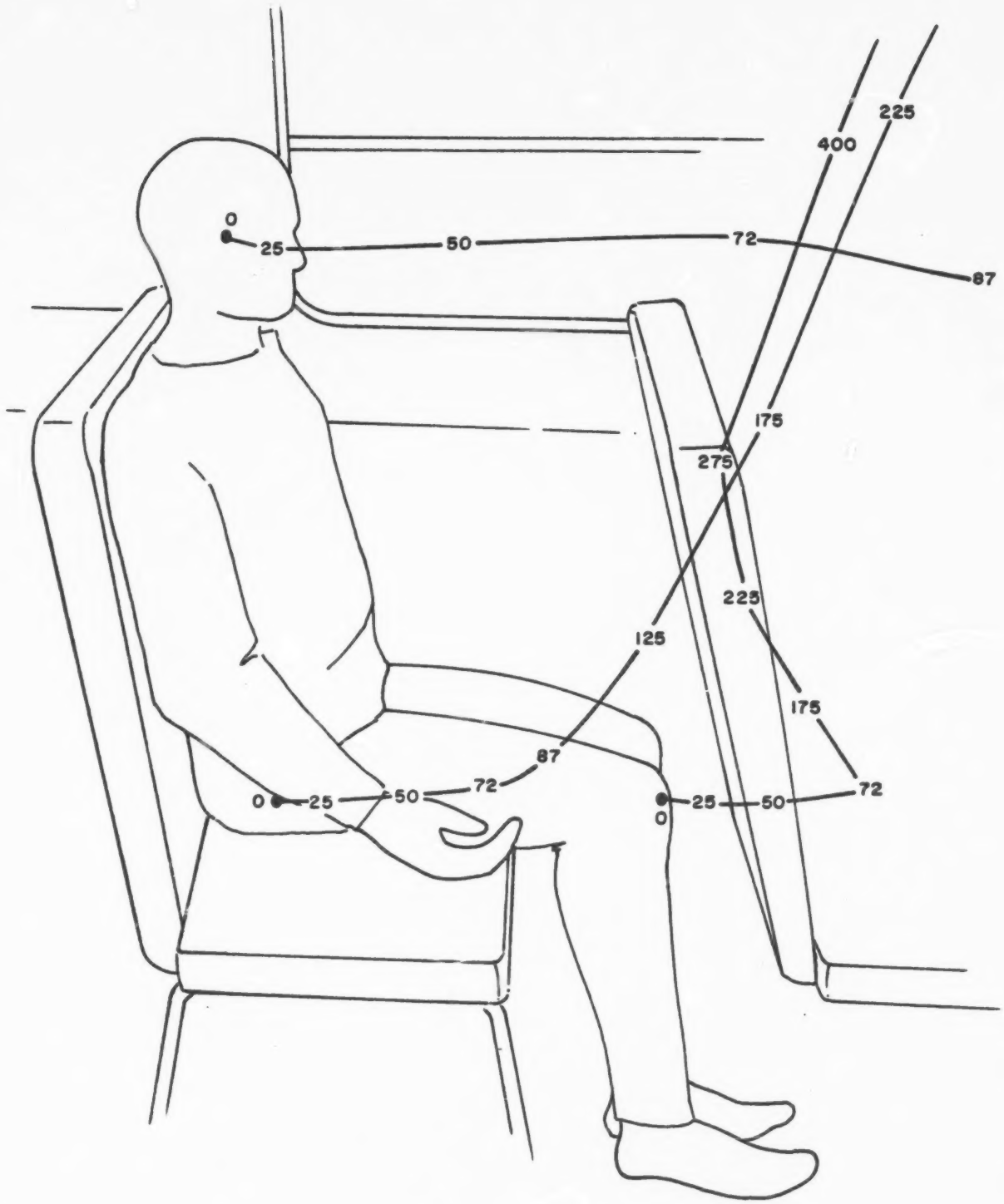


FIGURE 3-47. FORWARD FACING 50TH PERCENTILE MALE IN A SMALL SCHOOL BUS

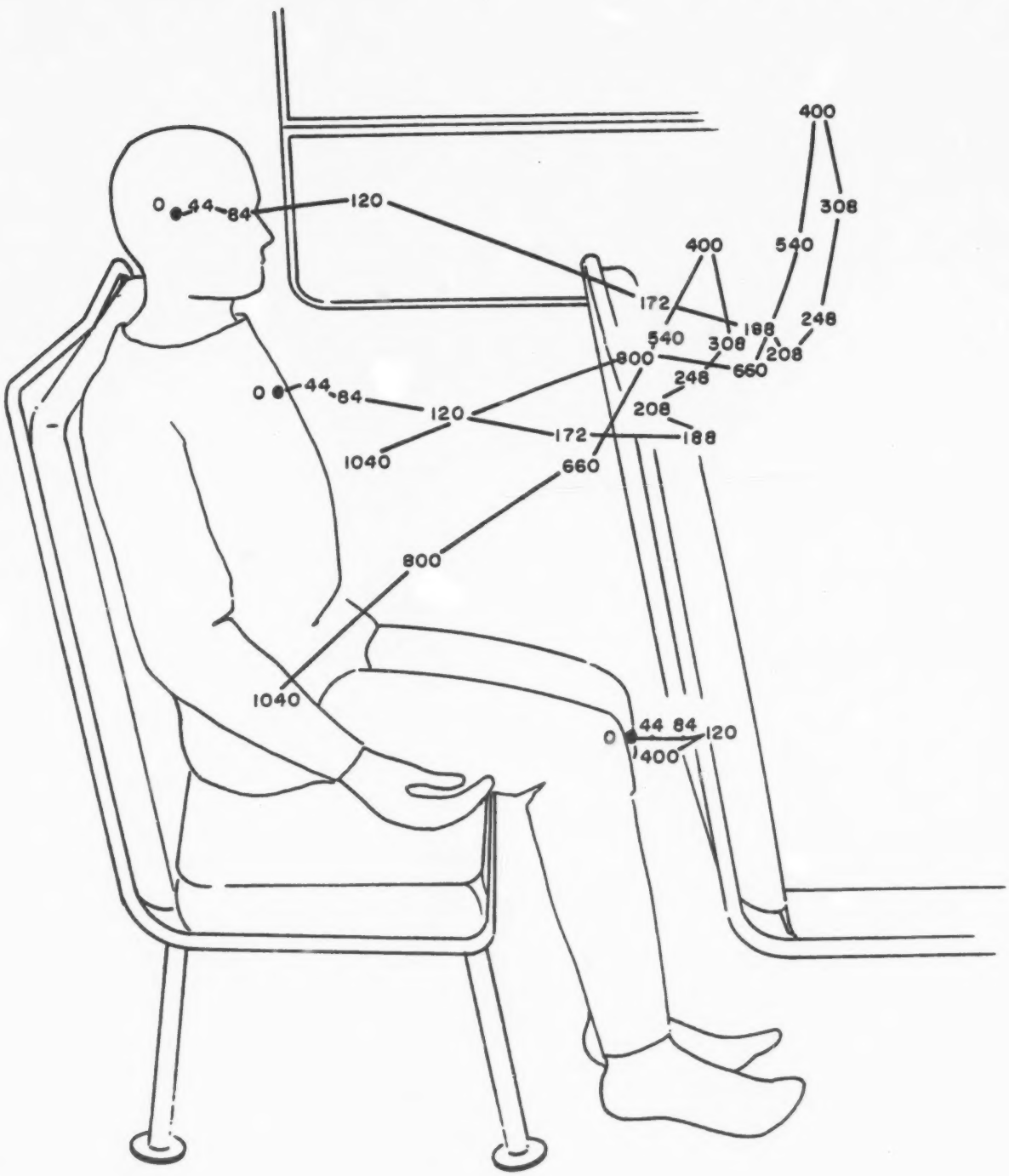


FIGURE 3-48. FORWARD FACING 50TH PERCENTILE MALE IN A TRANSIT BUS

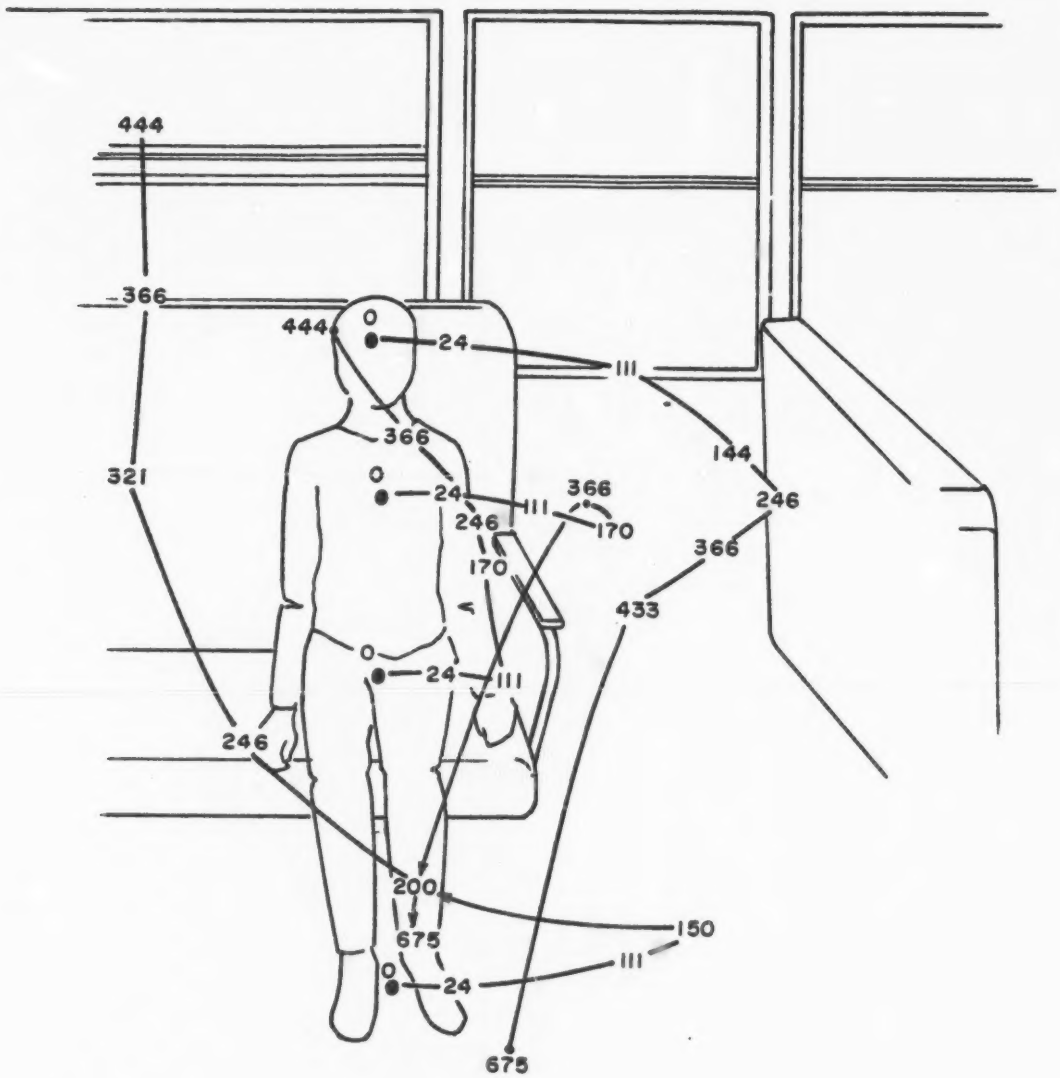


FIGURE 3-49. SIDE FACING CHILD IN A LARGE SCHOOL BUS

the armrest, which acts as a temporary restraint. Upon hitting the armrest at 111 msec the dummy's hip stops, but his upper torso and the legs continue moving. At 150 msec the dummy is bent in a sideways U around the armrest. His upper torso then continues in the same direction while his legs begin to move backwards. This causes the dummy to somersault in the air. At 675 msec his head first contacts the ground, and the rest of his body follows (Figure 3-49).

Trajectory 5 – Side Facing 50th Percentile Adult Male Dummy in a Large School Bus. A 50th percentile male is sitting unrestrained in a side facing seat (Figure 3-50). At impact the dummy slides toward the armrest. At 107 msec the dummy impacts the armrest, but his weight causes the armrest to bend. By 206 msec the dummy is diving head first (feet rising and head falling) until he hits the floor. It was evident that the armrest is ineffective against the weight of an adult.

Trajectory 6 – Side Facing Child and 50th Percentile Adult Male Dummies in a Large School Bus. A 50th percentile male and a 6-year-old child are sitting side by side in a side facing seat (Figure 3-51). The child is in the forward section of the seat. Neither dummy is restrained. When the bus impacts the barrier the dummies begin to move. Both move at the same rate until the child contacts the armrest. At this point 83 msec has gone by. The 50th percentile male continues moving into the child squeezing him until the armrest begins giving way at 100 msec. As the armrest continues bending both dummies slide off the seat and onto the floor.

Trajectory 7 – Side Facing 50th Percentile Adult Male Dummy in a Small School Bus. The 50th percentile male is in a side facing seat with a 6-year-old child between him and the wheelchair lift support (Figure 3-52). As the bus impacts, the 50th percentile male dummy slides forward. At the same time, a child dummy next to the adult fell forward and out of the path of the adult. With the child out of the way, the adult's head strikes the lift bracket at 42 msec. By 52 msec he begins falling toward the aisle with the child beneath him.

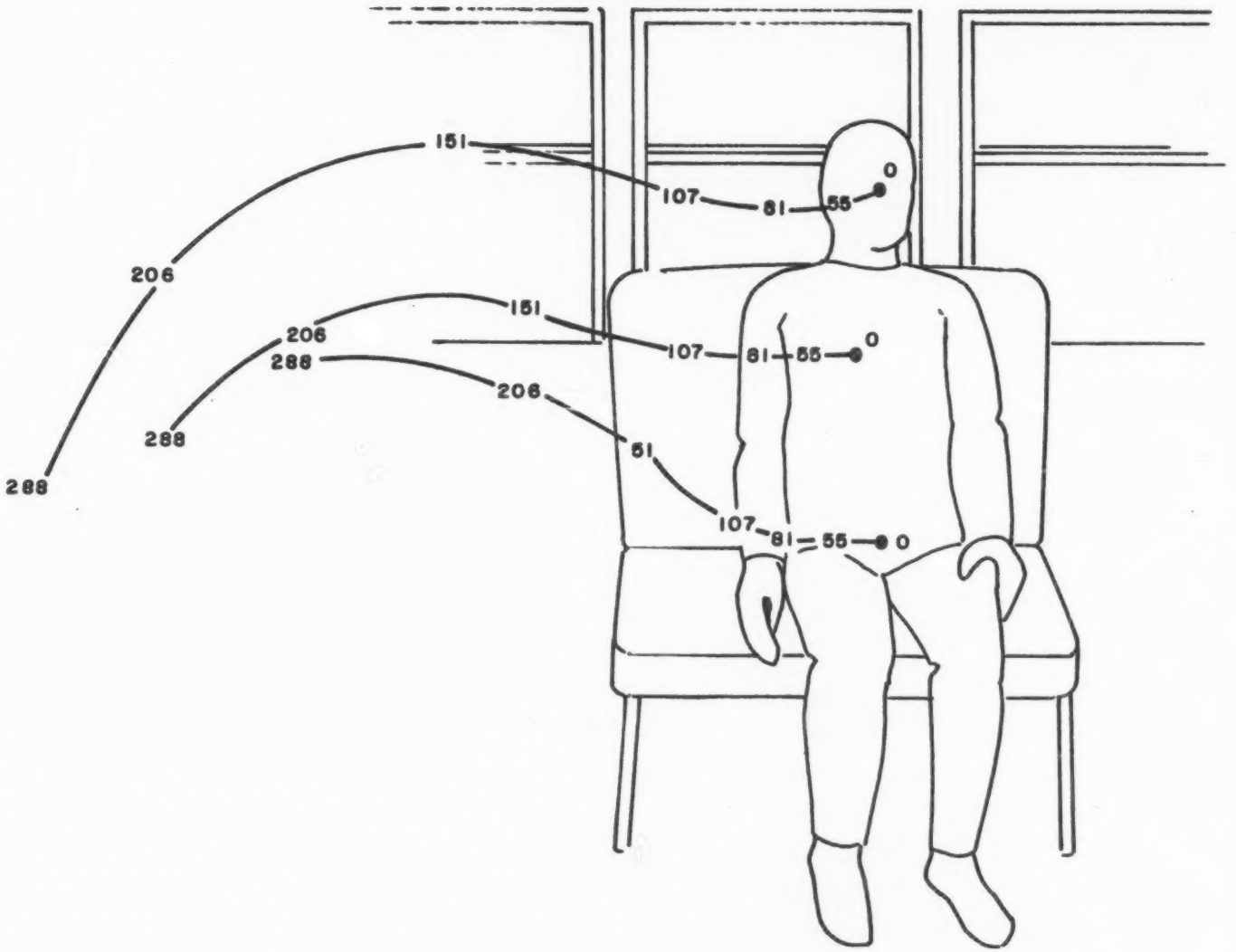


FIGURE 3-50. SIDE FACING 50TH PERCENTILE MALE IN A LARGE SCHOOL BUS

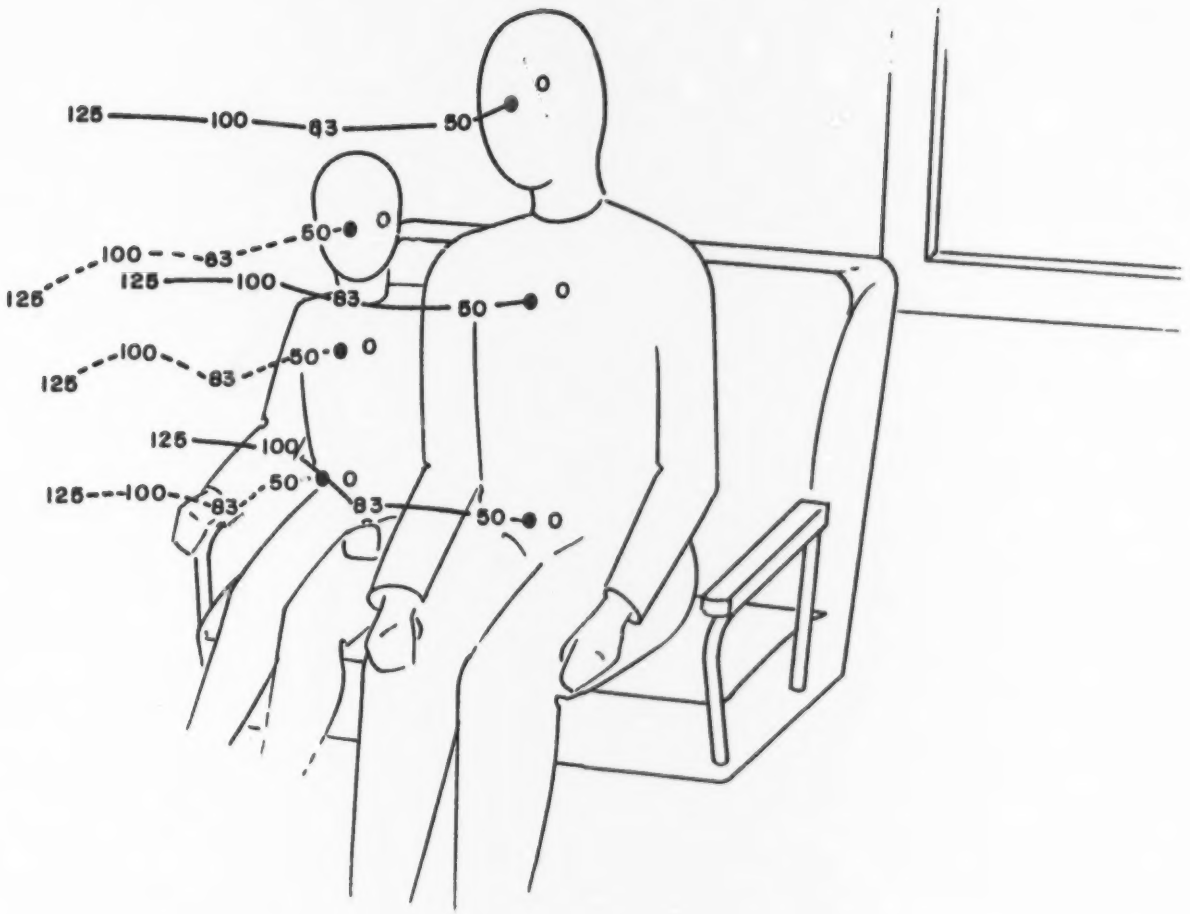


FIGURE 3-51. SIDE FACING CHILD AND 50TH PERCENTILE MALE IN A LARGE SCHOOL BUS

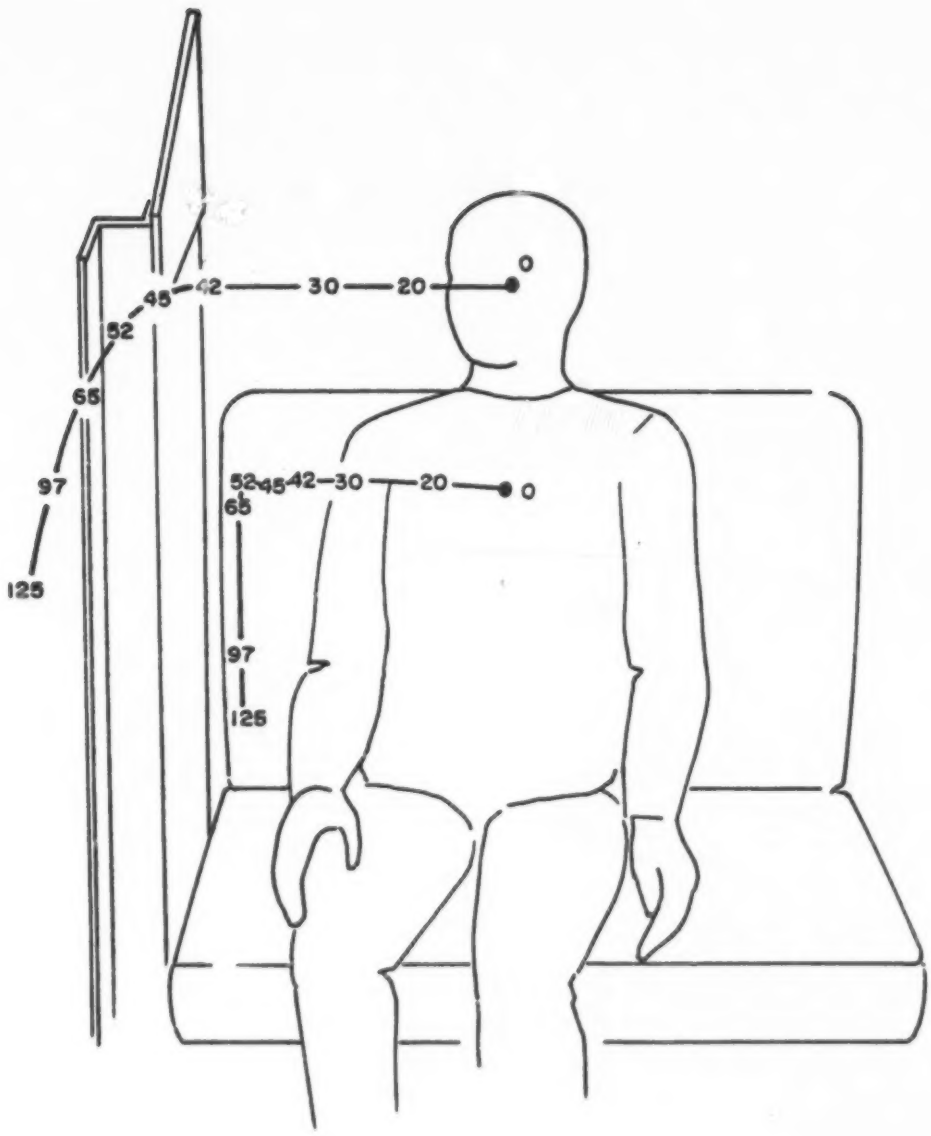


FIGURE 3-52. SIDE FACING 50TH PERCENTILE MALE IN A SMALL SCHOOL BUS

Side, Rear and Forward Facing Wheelchairs

Trajectory 8 – 50th Percentile Adult Male Dummy in a Side Facing Wheelchair in a Large School Bus. The 50th percentile male dummy is occupying a side facing wheelchair which is restrained by a three point cargo belt system mounted on the floor (Figure 3-53). The dummy is secured to the wheelchair by a lap belt. As the bus impacts the barrier, the dummy begins to move toward the seat back next to him. The wheelchair begins to buckle at about 16 msec allowing the dummy to continue moving. While the wheelchair is buckling, the dummy's shoulder strikes the seat back. By 125 msec the dummy's full force is against the seat back and the seat back is flexing, and the dummy is starting to rise upward. At 166 msec he has stopped rising and begins falling toward the aisle. His head and shoulders fall forward onto his lap.

The lap belt prevented the dummy from leaving the wheelchair but the buckling of the wheelchair allowed him to strike the seat back with force. The seat back acted as a restraint and prevented the dummy from going further forward.

Trajectory 9 – 50th Percentile Adult Male Dummy in a Forward Facing Wheelchair in a Transit Bus. The 50th percentile male dummy is sitting in a forward facing wheelchair which is secured by a T-bar system (Figure 3-54). The dummy is belted to the wheelchair with a lap belt. Both the securement device and the lap belt restrained the dummy. When the bus crashes against the barrier, the dummy begins his forward motion. There is little motion or buckling of the wheelchair during the crash. At 140 msec the dummy's shoulders and head have stopped moving forward, but continue in a downward arc toward his knees. The upper torso stops moving at 240 msec. The dummy did not strike any part of the bus during the crash, since neither the T-bar restraint nor the lap belt failed.

Trajectory 10 – 50th Percentile Adult Male Dummy in a Forward Facing Wheelchair in a Large School Bus. The dummy's seating position (Figure 3-55) is the same as in Trajectory 9, but this time the wheelchair is secured with the Carpenter Securement System. The reaction of this dummy is the opposite extreme of Trajectory 2. The wheelchair breaks away from the securement device almost immediately upon impact. At 37 msec the wheelchair is fully loose, allowing the

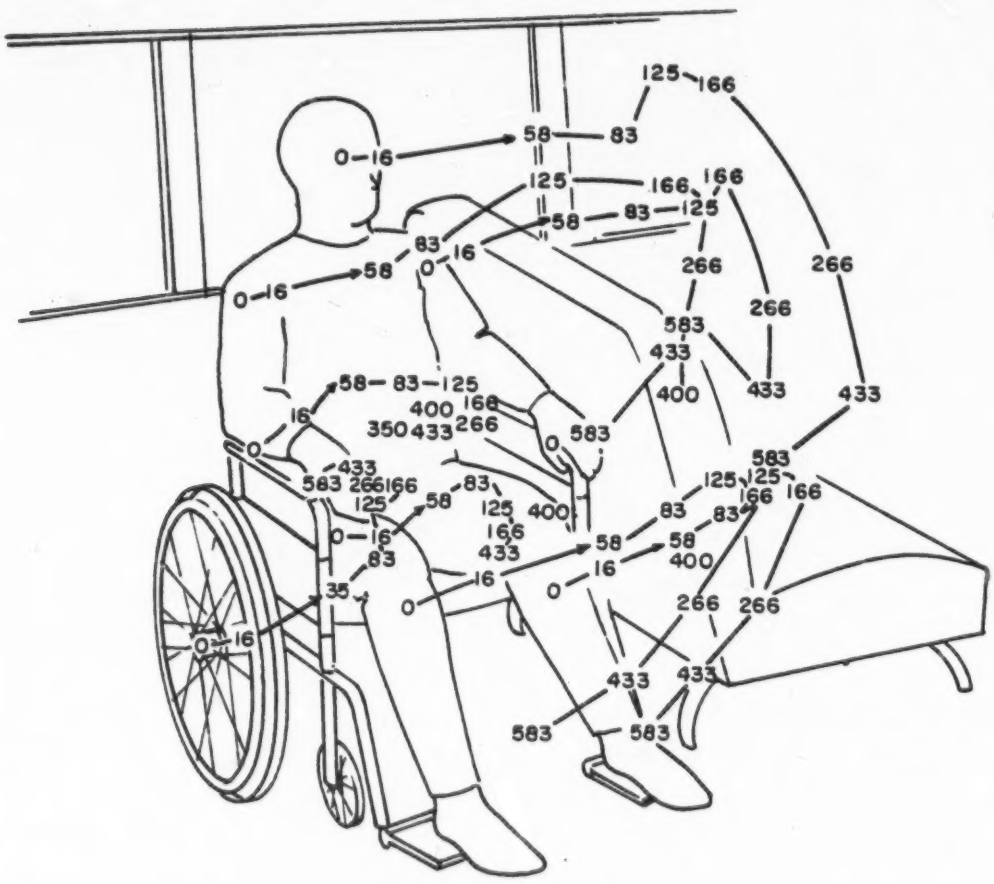


FIGURE 3-53. SIDE FACING 50TH PERCENTILE MALE IN A LARGE SCHOOL BUS

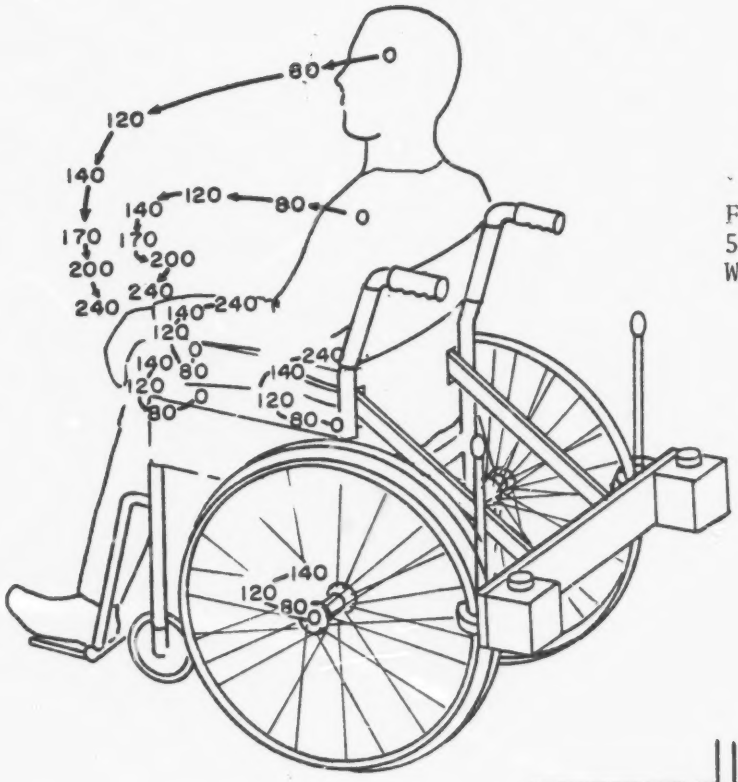


FIGURE 3-54. FORWARD FACING 50TH PERCENTILE MALE IN A WHEELCHAIR IN A TRANSIT BUS

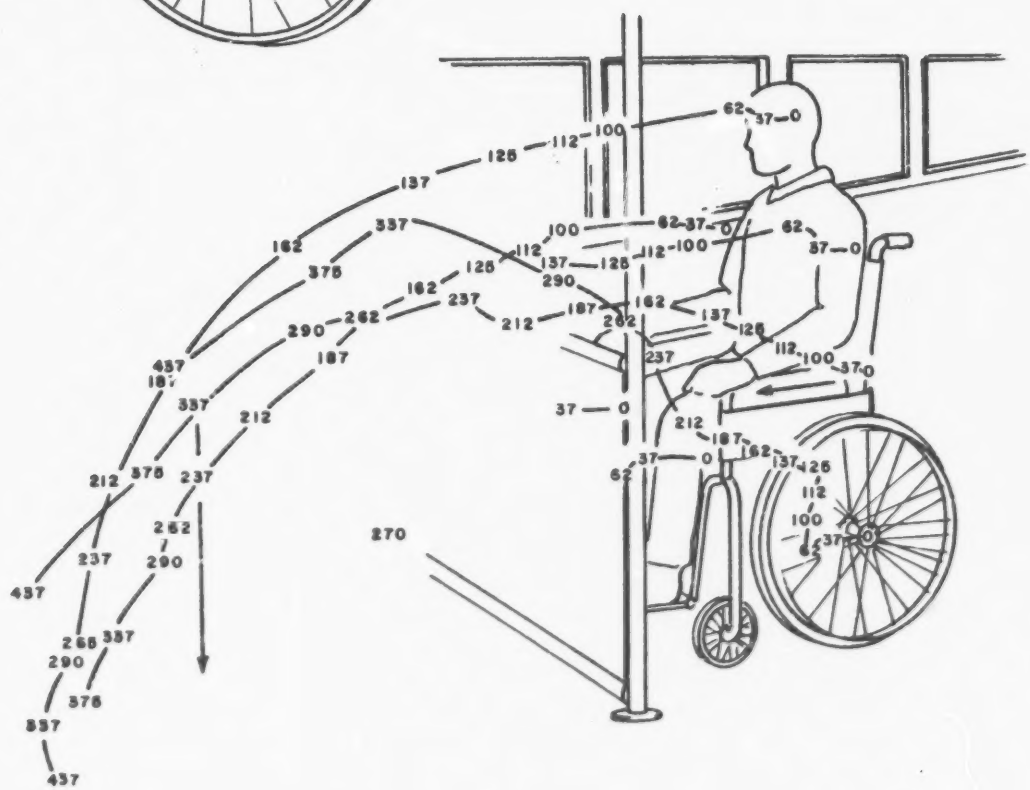


FIGURE 3-55. FORWARD FACING 50TH PERCENTILE MALE IN A WHEELCHAIR IN A LARGE SCHOOL BUS

dummy, who is still belted to the wheelchair, to continue moving forward. By 162 msec the dummy's shoulders have struck the barrier panel and he is beginning to roll over the top. The dummy and wheelchair continued on over the barrier panel and hit the floor head first at about 270 msec. This is an excellent example of the reaction an unrestrained wheelchair would undergo. The barrier itself was insufficient to stop the wheelchair.

Trajectory 11 – 50th Percentile Adult Male Dummy in a Rear Facing Wheelchair in a Small School Bus. The rear facing wheelchair (Figure 3-56) is attached to rim pins fixed to a bracket coming up from the floor. The dummy is lap belted to the wheelchair axle bolts. As the bus impacts the barrier, the dummy begins moving upward out of his seat. By 25 msec he has reached his peak

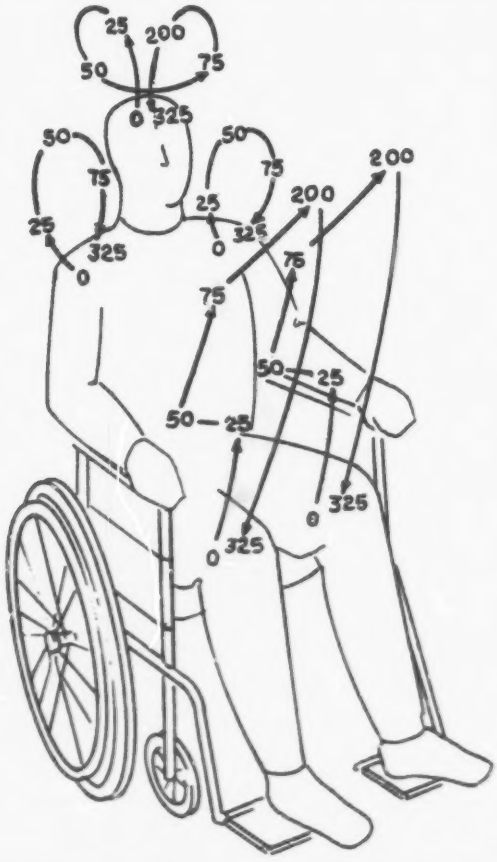


FIGURE 3-56. REAR FACING 50TH PERCENTILE MALE IN A WHEELCHAIR IN A SMALL SCHOOL BUS

height. The dummy begins moving downward at 200 msec. There is a padded stanchion directly behind the dummy which prevents movement toward the front of the bus. The force of the dummy bent the stanchion considerably and there was some deformation of the wheelchair. The dummy's knees moved upward, but eventually returned to their original positions.

Driver

Trajectory 12 – 50th Percentile Adult Male Dummy in the Driver's Station in a Large School Bus. The driver is a 50th percentile male belted to a single seat (Figure 3-57). As the driver begins moving forward the dashboard and steering wheel are moving backward. For the duration of the impact the steering wheel is pushed into the dummy's stomach. At 67 msec the dummy's head strikes the cement barrier and remains pressed against it until 104 msec. A this point both the chest and head begin rebounding. The dummy ends up in his initial seating position.

3.2.3.5 Dummy Injury Levels

As described earlier during the test procedures, each test bus had up to seven instrumented dummies at various seating positions. The dummies were conventionally instrumented, yielding measurements of chest acceleration, Chest Severity Index (CSI), head acceleration, Head Injury Criteria (HIC), and femur and belt loads. The details are completely presented in the individual test reports in Appendices E, F and G. A summary of the results is given in Table 3-7. The results listed in the table are arranged by individual test, in the order in which they were conducted. For each test the data include the following seating positions:

- Forward facing seats
- Side facing seats
- Wheelchairs
- Driver's station.

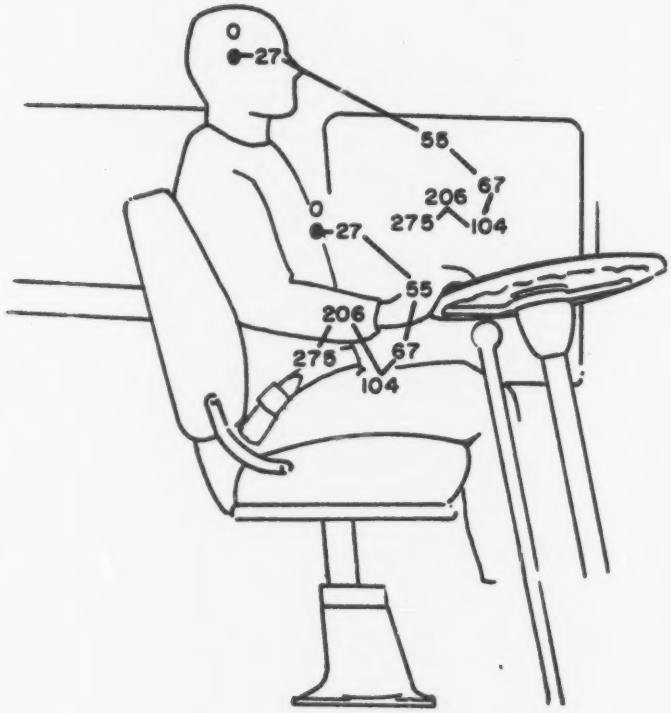


FIGURE 3-57. DRIVER IN A LARGE SCHOOL BUS

Forward Facing Seats

Test dummies placed in forward facing seats fared relatively well during all three modes of impact (front, side and rear), when FMVSS 208 injury criteria are applied for the threshold of injury tolerances. The only exception to this was a 6-year-old child dummy in the Thomas Mighty Mite school bus. It experienced a HIC measurement that exceeded the criterion accepted for the 50th percentile adult male dummy. Apparently, the seat back padding designed for the FMVSS 222 criterion is too stiff for a 6-year-old child. But it should be noted that the test in which this occurred was conducted at a barrier impact speed above 30 mph.

Two small school buses were tested during the program: a Thomas Mighty Mite and a Wayne Busette. The latter is classified as a Type II school bus, and the dummies in that bus were restrained with lap belts. A comparison of the data taken from these two buses indicates, in general, low injury measures when seat belts were used to restrain the dummies.

A comparison of the data from the small and large school buses indicates that injury measures in large school buses are substantially lower than those found in small school buses. This result was expected, since the large school bus front impact tests were conducted at 21 mph and those of the small school buses were at 30 mph. The resulting deceleration crash pulses were substantially more severe for the small school buses.

A comparison between the performances of dummies placed in forward facing seats in large school buses and those in transit buses shows that, in general, in the large school bus the FMVSS 222 seats did a better job of containing the dummies within the seating space. However, the HIC and CSI for most dummies were somewhat lower for the transit buses, than those seen in the large school buses. The results are certainly consistent with the severity of the crash pulses. The transit buses, with their rear engine configurations, had somewhat softer deceleration crash pulses than did the front engine school bus. The pulse of the unitized construction, mid-engine Crown Coach school bus was between the pulses of the transit buses, and the Carpenter bus.

The dummies in the forward facing seats experienced relatively very low injury measures in the side impacts. The HIC measurements were especially low. As expected, the unrestrained dummies had nothing to contain them on the seats and usually ended up on the floor. Nevertheless, the resulting CSI and HSI values were very low.

The dummies in the forward facing seats of the two small school buses experienced relatively low injury measures in the two rear impact tests. In such rear impacts, the 50th percentile adult male dummies experienced somewhat higher HIC number and chest loads than did the 6-year-old child dummies. The higher seat back appeared to support and contain the child much better than the adult.

Side Facing Seats

In all of the test buses, the dummies in side facing seats had, in general, poorer performance in front impacts. The 6-year-old child dummies had higher injury measures than those experienced by the 50th percentile adult male dummies.

The adjacent bariers and FMVSS 222 seat backs did not provide adequate protection during front impacts. In two cases the HIC measurement for the 6-year-old child dummy exceeded 1000 (the threshold of injury tolerance for the 50th percentile adult male). In both cases, the inadequacy of the FMVSS 222 seat back was further magnified by the fact that a 50th percentile adult male dummy seated next to the child dummy struck the child during the test, pinning him against the seat back. The conventional armrest could not hold the two passengers in the seat (in fact, it failed structurally very early in the impact event).

The dummies in the side facing seats generally ended up on the floor. However, that secondary impact did not result in substantial deceleration levels or HIC and CSI measurements.

The side and rear impacts did not produce high injury measures. Head, chest and femur/belt load injury measures were very low in those impacts. At times they were insignificant.

Wheelchairs

The test buses included wheelchairs in three different orientations: forward facing, side facing and one rear facing wheelchairs. In each case the dummy was restrained with a seat belt firmly anchored to his wheelchair structure.

Forward Facing Wheelchairs. The injury measures recorded for dummies in forward facing wheelchairs were comparable with those experienced by an adult unrestrained dummy in a forward facing seat. The injuries occurred primarily when the wheelchair securements failed or permitted excessive excursion. Excessive excursion allowed the dummy to strike bus hardware in front of him. The securement systems attached to the wheels of the wheelchair performed very poorly. The wheels were distorted as their spokes failed, and this allowed the wheelchair seated dummy to travel excessively. Those systems attached to the structure of the wheelchair performed somewhat better.

The commercially available systems for the transit buses (American Seating, Flxible and Collins) had acceptable performance only when safety belts were used

to restrain both the wheelchair and the dummy. The safety belt system was used in addition to the wheelchair securement systems. When the securement systems were tested without the safety belts, the systems in each case failed to adequately secure the wheelchairs.

Side Facing Wheelchairs. In front impacts the dummies in side facing wheelchairs generally had higher injury levels than did those in forward facing wheelchairs. The high values again depended more on the degree of failure of the securement than on the type of bus. The high values of the Wayne Busette dummy were due to the failure of the wheelchair wheels, permitting the dummy to impact the seat back to his side. The dummies in the two smaller buses had much higher injury levels than did the dummies in any of the other buses. The Thomas bus passenger incurred severe injuries.

The side and rear impacts produced injury levels which were significantly lower. The Thomas passenger who suffered severe injuries in the front impact sustained very minor injuries in the rear impact. The other buses had similar results, but with lower values.

Rear Facing Wheelchair. The only rear facing wheelchair was in the Wayne Busette. In both front and rear impacts the injuries to this dummy were considered minor. The HIC measurements in the front impact were higher because there was a padded stanchion directly behind the dummy's head.

Driver's Station

The driver dummy was instrumented in only a few tests, and the results in these tests were very similar. In all cases the dummy was a 50th percentile adult restrained with a lap belt. The primary injuries in front impacts were to the head and chest. The steering wheel and dashboard were pushed rearward into the forward moving dummy. The dummy's head struck the windshield, and, in the rear and mid engine buses, the driver's head directly hit the concrete barrier. When that occurred, the resulting injury levels were far higher than the accepted injury threshold.

Injury levels in the side and rear impacts were judged to be fairly low and comparable to the ones experienced by the passenger dummies.

3.2.3.6 Additional Information

The Carpenter conventional school bus frontal test appears twice in Table 3-1. The first test experienced instrumentation malfunctions and the major portion of the data was lost. Hence, the test was reconducted using another test bus. Enough test data were available to make a comparison between deceleration crash pulses and the actual damage between the two tests. The results indicate that, in general, the test results were quite similar.

Another mishap occurred when the Crown Coach Unitized school bus test missed the target speed for the front impact test. The actual test speed was 15.7 mph, instead of the target speed of 21 mph. After several alternatives were considered, a decision was made to reconduct the test at 21 mph with the slightly damaged test bus. Hence, Table 3-1 includes two front impact tests for the Crown Coach bus. The actual deceleration crash pulse for the Crown Coach bus was derived from the two available deceleration crash pulses – one at 15.7 mph and the other at 21.0 mph.

During this test program the small bus front impact tests were conducted at 30 mph and the large bus tests at 21 mph. It is of interest to find out how the deceleration crash pulses for small and large buses compare at the same speed. A comparison was made by deriving a 20 mph deceleration crash pulse for a small bus by interpolating from its 30 mph crash pulse and its time-displacement curve (using the amount of crush and the kinetic energy at the two speeds). The resulting 20 mph deceleration crash pulse was compared with a large bus 21 mph deceleration crash pulse. The results show that the crash pulse of the small bus at 20 mph appears to be somewhat softer than that of the large bus. The actual procedure used to derive the lower speed crash pulse is explained in the following paragraphs.

It has been shown that the duration of an impact does not vary significantly with speed for a given type of vehicle. What varies is the distance the vehicle crushes and the amount of energy dissipated. The crush can be predicted for

different speeds via the crush at a particular speed. Figure 3-58 was used to predict the crush at 20 mph from the crush at 30 mph by plotting the time-displacement curve at 30 mph and drawing a straight line from the speed the crush begins (about 2 mph) to the peak crush point. After superimposing a speed scale over the time scale, the crush at 20 mph is found by reading the value of crush (where the straight line crosses the 20 mph line).

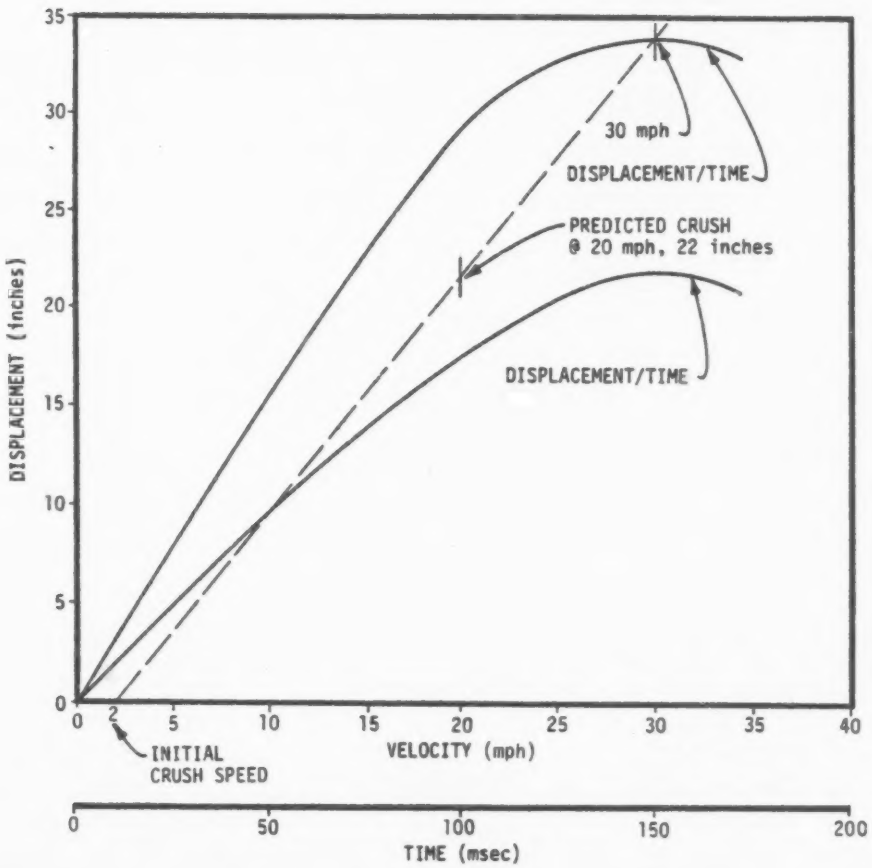


FIGURE 3-58. DISPLACEMENT/TIME CURVE OF THE SMALL BUS

The new pulse at 20 mph is found from the reduction in kinetic energy. The area under the deceleration-time curve is the amount of energy dissipated in the impact. The reduction in area under the deceleration curve is equal to the reduction in kinetic energy due to the speed change. The deceleration values are thus reduced by the percentage drop in kinetic energy form 30 mph to 20 mph. Figure 3-59 shows the 30 mph and 20 mph pulses.

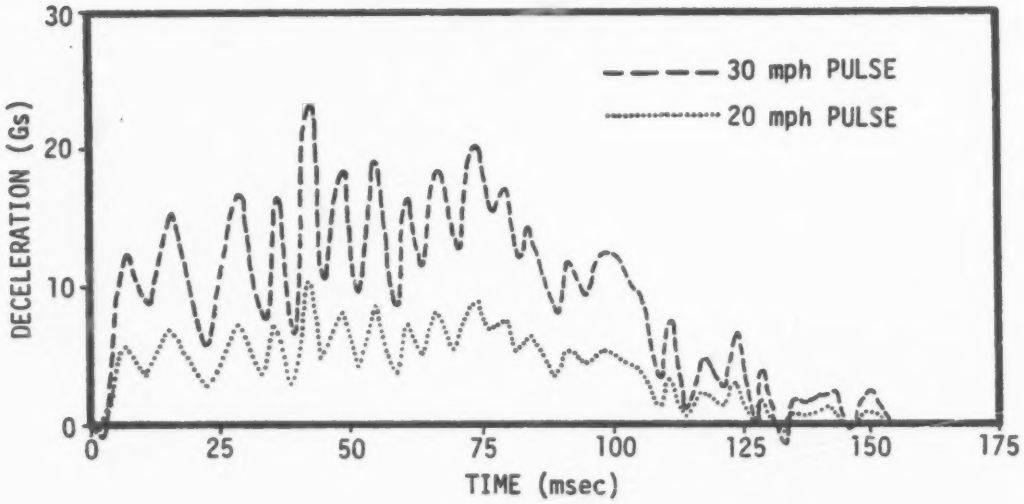


FIGURE 3-59. ACTUAL (30 MPH) AND CALCULATED (20 MPH) CRASH PULSES OF THE SMALL BUS

The school buses tested (with the exception of the Crown Coach Unitized Construction school bus) had a separate chassis and body construction. During a front or rear impact the body had a tendency to move in the direction of impact force with respect to the chassis. The general method used to anchor the body to the chassis was to use a series of metal clamps on the chassis longitudinal frame members. A friction material was placed between the chassis and the frame members. A relative chassis/body movement of up to 8 to 10 inches was observed on the Carpenter school bus test. This motion had an effect of reducing the distance between the driver dummy (who moved with the body) and the steering wheel (which was connected to the steering gear on the chassis, and therefore stopped much sooner than did the vehicle's body).

The derived composite pulses were obtained by taking the representative pulses for each bus after those pulses affected by floor deflections were eliminated. Filtering eliminated the extraneous vibrations of the bus and allowed the engineers to concentrate on the general shape and magnitude of each curve. These pulses were filtered by hand and by computer.

The hand method of filtering is a technique of curve smoothing employing the selection of median points. The process is used three times per curve. In the first two times the median of a point and a point on the curve to each side of it is taken. In the third time two points on each side of the selected point are used.

The computer program filtered the pulses at 60, 30 and 15 Hz, depending on the amount of high frequency fluctuations in the curve. The results are shown in Appendix D.

SECTION 4
CONCLUSIONS AND RECOMMENDATIONS

The conclusions drawn from the State-of-the-Art Survey (Task 2, Section 1), Injury and Fatality Data Analysis (Task 3, Section 2) and the bus crash tests (Task 4, Section 3) are presented together in this section. At the end of the section a series of recommendations are listed.

4.1 STATE-OF-THE-ART SURVEY

Equipment

- All sizes of buses are used by school bus operators for the transportation of handicapped students.

- Most school districts prefer to use specially designated buses for the exclusive use of handicapped students.

- In general, ramps are used in the small size school buses. They are not negotiable by a wheelchair occupant without assistance. The large buses, and even some of the small buses, have lifts.

- Cargo tiedowns appear to be the most commonly used wheelchair securement systems. Various types of rim pins and clamps are also in use on school buses. All of these require assistance.

- In a school bus environment the driver is available and trained to assist the wheelchair seated passengers.

- Wheelchair stations in school buses are located, for convenience, close to the ramp or lift. Such locations can be found at different locations in the bus and no single common area can be identified.

- The commonly used wheelchair orientations are forward facing, side facing and rear facing. The rear facing orientation is less frequently used because the passengers do not like traveling that way.

- No standard restraint system was found for the wheelchair passenger. Rather, the only common practice was not to provide a restraint system at all. At times a single belt anchored to the floor is used to restrain both the wheelchair and the passenger.

- The transit bus practices for the transportation of the handicapped differ widely from those found on school buses.

- In fixed route intracity transit bus operation, the full size large buses are generally used. The first two seats on both sides of the bus are side facing seats, generally designated for elderly and handicapped passengers.

- To create two wheelchair stations, the next two forward facing seats on either side of the transit bus are removed. Generally, the wheelchairs are forward facing.

- The entry to the bus usually is by a step/platform lift. The driver does not provide assistance to the passenger in a wheelchair other than activating the lift.

- The actual number of wheelchair users riding the fixed route transit buses was found to be very low. (Since our early findings, the ridership might have increased with the increase in available lift equipped buses.)

The important conclusions of the State-of-the-Art Survey are summarized below.

Standards and Regulations – Crash Protection

FMVSS 222 specifies crash protection for school bus occupants. Energy absorbing padding is required on seat backs, stanchions and modesty panels. Seats must be forward facing, with a specified maximum distance between them.

In addition to the Federal standards, some state governments impose their own regulations. In California, for example, the state standards describe equipment and procedures for transporting wheelchair seated passengers. The primary deficiency in the California regulations is in the performance requirements for the wheelchair securement devices. Requirements for operating the devices and for attaching them to the bus exist, but performance standards for the devices themselves are lacking. The adequacy of the present devices is not known.

Most of the regulations are generally accepted as necessary and useful, although some people question the practicality of the maximum of 20 inches, allowed between seats. Many high school students are too large to fit into this space (in fact, the maximum distance was recently changed to 21 inches for this reason). The bus manufacturing industry also complains about the new regulations imposed and claims that school buses are already safe.

Transit bus standards on crash protection for passengers are almost nonexistent. In FMVSS 208 the only requirement is that the driver wear a seat belt.

Transportation Needs of the Handicapped

Approximately 5 percent of the U.S. population is transportation handicapped in some way. About 5 percent of these people are confined to wheelchairs. Other disabling handicap conditions include blindness and partial blindness, hearing problems, severe arthritis, temporary illness or injury, heart problems, etc. Handicapped persons tend to have less access to automobiles than the general public, and thus have lower employment rates than others. Improved transportation for handicapped persons (both transit and school bus) will likely improve this situation by providing better access to work, education, shopping and recreation. It would allow these persons to be less isolated, as well as provide opportunities for them to enjoy a more varied lifestyle.

Problems associated with the present systems vary, depending on the physical capabilities of the handicapped person using the system. Most communities have school buses or vans with lifts or ramps and restraints for wheelchair-confined and other handicapped people. Loading devices that seem relatively safe and

efficient are available, although many school buses have only ramps or lifts that must be partially manually operated (and thus are physically demanding on bus drivers). Several types of wheelchair tiedowns are commercially available. These have been tested and evaluated for safety and performance capabilities. However, there is no accepted design and performance standard to evaluate them. According to research conducted at Wayne State University, no existing system provides adequate protection for handicapped passengers on buses. The Wayne State study also revealed that many wheelchair securement devices are also slow and awkward to attach. For school buses, it is not necessary (and in some cases not a good idea) to permit the wheelchair occupant to operate the restraints. But, because handicapped children have such diverse needs, capabilities and physical limitations, it is difficult to design a single crash protection system for handicapped school buses that satisfies every individual requirement. The best that is available today (which may be adequate in many cases) is padded seats and seat belts.

Needs for safety provisions on transit buses will likely differ from those required for school buses. Since one-third of the handicapped need door-to-door service, they could not use normal fixed route buses even if the buses are provided with special equipment. Some communities have special ride services for the elderly and handicapped, but many have no public transportation that can accommodate wheelchairs. For the ambulatory handicapped, lower floors and steps are needed. For wheelchair-seated riders, wide aisles, space allocation, and safe securement systems are required. In contrast to school buses, the securing devices should be operable by the person in the wheelchair. These devices must, therefore, be within easy reach and not require unusual strength for operation. A lift or ramp is necessary for loading and unloading. The type and placement depend on the intended use. Ramps should have no more than a 10 percent incline. On buses that provide special handicapped services, a lift and/or ramp either on the side or in the rear is sufficient because the driver/operator can provide assistance. For fixed route or mixed passengers (handicapped as well as non-handicapped riders), it is usually preferred that the lift/ramp be used with the standard door at the right front of the bus. This door must, therefore, be wide enough for the easy passage of wheelchairs. In general, transit buses should be equipped to enable the handicapped to be more self-sufficient than would be required on school buses; in school transportation the driver is more likely to

know each passenger's needs and to provide the required assistance. In a transit system (especially on a fixed route bus) such personal attention usually is not possible.

Desired Characteristics of Equipment

Based on the information compiled, we have concluded that the desired characteristics of handicapped transportation equipment differ markedly for school buses and for transit buses. Further, transit buses should be separated into those on fixed routes which have a mix of handicapped and non-handicapped passengers, and those that provide demand-responsive service specifically for the handicapped. School bus equipment lifts and wheelchair tiedowns are operated with bus driver assistance in accordance with Federal and State regulations. Transit buses that transport only the handicapped should have wheelchair tiedowns that can be operated by a capable wheelchair seated person, although driver assistance should be available, if needed. On a fixed route integrated transit system the boarding, maneuvering, and tying down of wheelchairs would have to be independent and efficient because of the operational requirements. The following list compiles the desired characteristics of the equipment used for the transportation of the handicapped. These characteristics are derived from recommendations and comments from collected data during the State-of-the-Art Survey.

- Conventional transit bus floors can provide adequate strength for the securement of interior fixtures and required safety hardware. Currently the nominal step height is 12 inches. If this height were reduced to 8 inches, indications are that ambulatory persons with handicaps would have significantly less difficulty mounting the steps. Steps should not have protruding edges which could cause tripping. An integral step/lift fixture would appear to resolve most loading difficulties.

- Conventional transit buses generally have a single entrance for the regulation of fares. For a fixed route transit operation the wheelchair loading device should be at the forward door in order to pass the fare box. School buses and special buses for the handicapped generally require an extra door with a

lift/ramp on either the side or the rear. Each of these locations has positive and negative points. A lift door on the rear often requires the wheelchair passenger to go into the street; on the other hand, its location inside the bus is less dangerous because the device is behind all the seating positions. Also, the fact that the bus has just driven over the loading area insures that the area is clear. Side doors may be preferred because they can open onto sidewalks and driveways, although the stowed equipment inside the bus could be a hazard in a collision. A curb or uneven surface could also cause difficulties if the bus cannot be aligned correctly with respect to it.

- Door widths of 29 to 38 inches are recommended for wheelchair access. Within this range the doors should be as wide as allowable by the bus structure and other space considerations.

- The seating positions specified in FMVSS 222 may be satisfactory from a safety point of view for transporting the ambulatory handicapped in forward facing seats. But some side facing seats may be required for handicapped persons who would have difficulty getting into and out of conventional forward facing seats. Additional protection (in the form of belt restraints for side facing passengers) is desirable. The seating in transit buses is satisfactory for the ambulatory handicapped, since the first two side facing seats are easily accessible and are designated for use by elderly and handicapped persons.

- Aisles in standard buses (both school and transit) are too narrow to accommodate wheelchairs. Aisles in buses that will carry wheelchairs must be widened to at least 29 inches to permit entrance, exit and easy accessibility to emergency doors.

- A cleared space of at least 25 by 41 inches, plus maneuvering space, is necessary for each wheelchair (Reference 60). To provide this space in most buses, seats would have to be removed or foldaway seats installed.

- The barriers as per FMVSS 222 are specified to provide adequate crash protection for forward facing passengers in school buses. Additional padding or barriers may be needed in front of the wheelchair-seating sections or side facing seats provided for the handicapped.

- Emergency exits are already required on all buses, but on buses carrying wheelchair passengers the exits should be at floor level and should be of sufficient dimensions to allow easy passage by a wheelchair.

- Securements should be installed for each wheelchair. Although exact performance requirements for securement devices are not yet known, the devices should be capable of holding an occupied wheelchair in position during front, side, rear and rollover crashes. They, therefore, should be secured to a sturdy structural part of the bus. Their operations must vary according to purpose. Securements for transit buses must be capable of being engaged and disengaged without requiring an unusual amount of strength. In school buses the levers and switches of wheelchair securements within reach of the wheelchair passenger need not be operable by the wheelchair occupant. Also, securements should be designed on the basis of the strong points of wheelchair structures.

- Wheelchair loading devices must be provided, since standard bus entries cannot accommodate wheelchairs. Ramp inclines must not be steep (1 foot of rise needs 10 feet of run), when unassisted use is intended. Unless a strong attendant (driver or other person) is available to push, ramps would be impractical. In most cases, a powered lift would be necessary. The following lift features are preferable:

  - A pressure sensing mechanism on the bottom of the platform so that the lift will stop upon contact with any surface or obstacle
  - A safety flap on the bottom of the platform to prevent wheelchairs from rolling off during lifting
  - A loose flap or other measure to prevent toes from being squeezed or jammed between the lift platform and the bus floor
  - A capacity of at least 400 pounds
  - A manual backup system, should the power system fail
  - Operating controls at three locations: the driver seat, within reach of the person on the lift, and beside the lift (for a driver or attendant outside the bus). In a fixed route transit bus, the lift/ramp should be located in the standard front doorway.

- Seat belts are not practical for most seated passengers in fixed route transit buses. Seat belts should be provided for ambulatory handicapped passengers on school buses, and on demand-responsive bus services for the handicapped and/or elderly. Most school buses and buses for the handicapped are presently equipped with such belt systems. Supportive and/or padded restraints should be available for pupils unable to support themselves upright while the bus is in motion.

- Side facing bench seats are more common in transit buses than they are in school buses. In transit buses the side facing seats are found on both sides near the forward entrance. In the rear of the bus they are usually placed over the wheelwells. FMVSS 222 has made side facing seats illegal on all school buses except for those that transport handicapped school children. Usually the small school buses and vans have such seats. These are generally placed in the rear portion of the bus, near the emergency exit. Seat belts or other containment features must be provided with side facing seats intended for use by the handicapped.

4.2 ANALYSIS OF INJURY AND FATALITY DATA

The most important conclusions of the analysis were:

1. The accident data collected did not include a single case in which a wheelchair seated passenger suffered a serious or fatal injury.
2. Frontal impacts (11, 12 and 1 o'clock) account for the majority of the fatal and serious bus accidents.
3. Single vehicle rollover and rollover after the initial impact are involved in a large percentage of the fatal bus accidents.
4. Seat backs, stanchions, windows and structural deformation (resulting from the accident) appear to be the primary elements of the bus that cause injuries to the bus occupants.
5. The driver's station is very susceptible to serious and fatal injury, particularly during frontal impacts.
6. The injuries and fatalities produced by an impact are usually concentrated in the immediate vicinity of the impact.

7. No accurate data were available on the speeds of the buses at the times of impact or on the relative velocities of impact (when two vehicles were involved in the accident).
8. In general, it appears that the selected test speeds for the bus crash tests are those most likely to produce severe injuries for bus occupants. (This is discussed in Section 3 of this report.)

4.3 DEVELOPMENT OF DECELERATION CRASH PULSES

Important conclusions from the bus crash test program are:

- Frontal fixed barrier impact tests were conducted at 30 mph for two small school buses and at 21 mph for all large school buses. The frontal impact tests of the small school buses produced the most severe deceleration crash pulses. However, a calculated deceleration crash pulse for a 20 mph frontal impact test of a school bus is comparable with the 21 mph crash pulses of the large buses. The comparison consisted of mean and average acceleration values.

- Side and rear impact tests produced, as expected, very soft pulses. This was especially true for seating locations which were two bays and further away from the point of impact.

- In general, the front engine buses produced more severe crash pulses than did the ones that had their engines located in the rear or underfloor.

- FMVSS 222 seat back did not appear to provide a 6-year-old child dummy the same protection that it affords a 50th percentile adult male dummy. The padding and the structure appeared to be too stiff for the child dummy.

- The wheelchair seated passenger dummies had injury levels comparable, in general, with those of the other passenger dummies seated in forward facing seats – as long as the wheelchair securement did not fail.

- The unrestrained dummies placed in side facing seats usually ended up on the floor after the crash event. However, they earlier had a hard impact with

either the adjacent seat back or a barrier. The conventional seat back or barrier does not provide the occupant of the side facing seat adequate crash protection. His trajectory and body motion require a different seat back or barrier shape to provide suitable protection.

- Wheelchair securement systems that secure wheelchairs at their wheel rims do not function well. The wheels usually fail and that allows the wheelchair and the passenger to have much longer excursion. This increases the probability of the passenger striking adjacent hardware.

- Some of the commercially available wheelchair securement systems did not perform well. In particular, three systems used on transit buses would require a supplementary safety belt to make their performance acceptable.

- In all of the test buses the driver was in a vulnerable position in a frontal fixed barrier impact. The most severe environment for him was in the rear engine large transit buses.

- The lifts and ramps are usually stowed inside the passenger compartment. The exposed structural members of these devices should be properly padded or a protective barrier should be installed between them and the passengers.

- The deceleration levels recorded at different locations in a bus were not identical. This might produce slight differences in the three sets of deceleration pulses of the test buses.

4.4 RECOMMENDATIONS

Accident Data

The conclusions led to a series of recommendations:

1. There is a lack of good quality data on bus accidents. We feel that the collection of such data (and their analysis) will aid the resolution of many safety issues, including:

- Which buses require what level of regulated safety protection that can be shown to be cost effective?
- What are the accident configurations that should be addressed to effectively enhance safety, at a justified cost increase?

2. Catastrophic bus accidents do generate detailed accident studies, but moderate and moderate to severe accidents are not thoroughly reported. A uniform accident reporting system would be beneficial.
3. Data collection formats do not generally address information that can identify injury causing mechanisms. The collection of related data would be valuable.

Equipment Used

1. Designers, manufacturers and users of equipment for the handicapped (such as wheelchairs, ramps, lifts and wheelchair securement systems) appear to have insufficient information about the safety implications of the systems used and the proper ways of employing them. The present report is a beginning. However, a better way of disseminating the information should be implemented. Such information will substantially enhance the convenience and safety of the handicapped passengers of buses.

2. The lack of consistent and informative guidelines for equipment design and use complicates the problem mentioned above.

3. School buses with separate chassis and body construction experience a relative motion between the chassis and body in both front and rear impacts. Several bus manufacturers claimed that this relative motion helps absorb some of the impact energy. It certainly makes the driver much more vulnerable (as explained in Section 3). To ascertain the advantages and disadvantages of this motion in accident situations, a more detailed quantitative analysis should be conducted.

Use of Deceleration Crash Pulses

Crash pulse data presented in this report will be quite useful for the design of bus structures and the interior hardware in buses. It is strongly recommended that the readers of this report also study the test reports (Appendices) before relying on the selected deceleration crash pulses presented in the text.

SECTION 5
FUTURE PLANS AND PROGRAM GOALS

The efforts expended thus far on the program have produced a massive amount of background information, including

1. State-of-the-art information on the equipment, practices and procedures being used by operators of school and transit buses for the transportation of handicapped people.

2. The results of a limited accident data analysis. This analysis provides data on the frequencies of accident types and their resulting injuries and fatalities. Detailed analyses of individual crashes have identified injury causing mechanisms and the bus interior and structural members that are likely to cause injuries.

3. A series of deceleration crash pulses of small and large school buses and large transit buses. In addition the test program has documented baseline performance at several seating locations, in a number of test buses and under selected test conditions.

This information will be extensively employed in the rest of the program. The remaining efforts will consist of a series of sled tests that will include the variation of several key parameters. The key parameters are those that have the most influence on the occupant protection system's performance. The key parameters that have been selected are given below:

1. Bus Size
   - Small and large school bus deceleration crash pulses will be used.
2. Passenger Size
   - A 6-year-old child dummy will be used to represent an elementary school child.
   - A 5th percentile adult female dummy will be used to represent a junior high school level child.

- A 50th percentile adult male dummy will be used to represent a high school level child.

3. Wheelchair Orientation
   - Forward facing
   - Side facing
   - Rear facing
4. Impact Mode
   - Front
   - Side
   - Rear
5. Wheelchair Securement
   - Belt arrangements
   - Solid securement on wheelchair structure
6. Passenger Protection Systems
   - Belts only
   - Padding only
   - Belt/padding combination
7. Passenger in Side Facing Seat
   - Variables 1, 2, 4 and 6 above will be investigated for side facing seats..

The results presented here (and the results to be obtained from the sled test program) will provide valuable baseline data for those involved in the design, manufacture and use of equipment selected for the protection of handicapped passengers of buses.

REFERENCES

1. Everest and Jennings, "Safety and Handling" – an informative brochure dated August 1978.
2. Everest and Jennings, "Everest and Jennings 177 Wheelchair Catalog," July 1975.
3. Everest and Jennings, "Everest and Jennings Premier Model Wheelchair Catalog," June 1975.
4. Everest and Jennings, "Power Chairs by Everest and Jennings," November 1978.
5. Telephone conversation with Mr. Keith Rodaway of Everest and Jennings.
6. Canyon Research Group, Inc., "A Requirements Analysis Document for Transit Vehicle Wheelchair Lift Devices," Contract DOT-UT-60106T, 1978.
7. Lakematic Inc., "A Powered Wheelchair from Lakematic," 1977.
8. Capital Development Board, "Accessibility Standards – Illustrated," State of Illinois, 1977.
9. Everest and Jennings, "Wheelchair Owner's Manual," June 1975.
10. Veterans Administration, "V.A. Standard Design and Test Criteria for Safety and Quality of Automatic Wheelchair Lift Systems for Passenger Motor Vehicles," June 1973.
11. Wayne Corporation, a brochure on School Buses, undated, unnumbered.
12. Blue Bird Body Co., several brochures on the full line of Blue Bird School Buses, undated, unnumbered.
13. Thomas Built Buses, a brochure on School Buses, undated, unnumbered.
14. Carpenter Body Works, several brochures on Carpenter School Buses, undated, unnumbered.
15. Grumman Corporation, a brochure on the Grumman Corporation Line of Airport and Transit Buses, undated, unnumbered.
16. Crown Coach Corporation, a brochure on the full line of Crown Coach Line of Motor Vehicles, undated, unnumbered.
17. Federal Motor Vehicle Safety Standard 222, "School Bus Seating and Crash Protection," Federal Register, Part 57; S-222
18. "Regulations and Laws Relating to Pupil Transportation in California," 1975 California State Department of Education.
19. "School Bus Fleet," a Bobit Publication. Published six times a year.

20. A telephone conversation with the Administrator, Dr. Dewey Brown, of The Bus Company of Santa Barbara, California.
21. RRC International Inc., "Small Transit Bus Requirements Study – Performance Specifications for Advanced Design: Small Urban Transit Bus," Contract DOT-UT-50006, March 1977.
22. J.F. Wing, et al, "Transbus – Current Developments in Urban Bus Design," Booz, Allen Applied Research, Inc., SAE Paper 730217.
23. J.W. Wetzel and K.R. Barnes, "Transbus – A Requirement for Urban Transportation," Rohr Industries, Inc., SAE Paper 730725.
24. J.F. Atkins, "Transbus – Testing and Public Evaluation (Around the country in 80 Days)," Rohr Industries, Inc., SAE Paper 750735.
25. HandiRamp, Inc., a brochure on Small Bus Ramps, undated, unnumbered.
26. Collins Industries, Inc., a brochure on the Collins Safety Ramp for small bus use, undated, unnumbered.
27. Collins Industries, Inc., a brochure on Collins Hydraulic Lifts, undated, unnumbered.
28. Braun Corporation, products brochure on Braun Lifts, undated, unnumbered.
29. Santa Clara County Transit District brochure showing a lift that swings out 90 degrees and then lowers to the ground.
30. Transportation Design & Technology, Inc., a brochure on the StepLift.
31. Collins Industries, Inc., a brochure on Step Conversion Lifts.
32. "Aeroquip Cargo Tiedowns," a brochure.
33. American Seating Co., informative pictures and material from the American Seating Co.
34. Grummann Flxible, informative pictures and material from the Grummann Corporation.
35. Collins Industries, Inc., informative brochure on SAF-T-LOCK.
36. Olson Industries, a brochure on their Wheelchair Securement System.
37. A fender support securement system used on "HandiTrans" buses in Santa Barbara, California.
38. Rim pin wheelchair securement used by the Wayne Corporation on their school buses.
39. T-Bar restraint system used on buses.
40. Douglas Ball Inc., "Wheelchair Restraint System – Design for MultiModes Transportation," July 1979.
41. Collins Industries, a brochure on the 'SAF-T-LOCK'.

42. "Double-Life-Savr" – a safety harness marketed for school bus use.
43. "E-Z-Harness" – a safety harness marketed for school bus use.
44. Everest and Jennings, a catalog for optional equipment for wheelchairs.
45. "Tye-Chair Restraint," a product advertisement in School Bus Fleet.
46. "Easy-Way," an article describing aftermarket padding addition to pre-FMVSS 222 seat backs.
47. School Bus Fleet, "Seat Construction Guidelines Require Extensive Lab Tests," August/September 1977.
48. School Bus Fleet, an editorial in the August/September 1977 issue.
49. California Association for Physically Handicapped (CAPH), telephone conversations and meetings with the group.
50. American Transit Association, "Urban Bus Design Objectives," October 1967.
51. Crain and Associates and Applied Resources Integration, Ltd., "A.C. Transit Elderly and Handicapped Planning Study – Analysis of Needs and Alternatives," September 1977.
52. RRC International, "A Study of Future Paratransit Requirements," Final Report.
53. Urban Mass Transportation Authority (UMTA), "Bus Characteristics Needed for Elderly and Handicapped in Urban Travel," March 1976.
54. Crain and Associates, "Transportation Problems of Transportation Handicapped," August 1976.
55. RRC International Inc., "Small Transit Bus Requirements Study," December 1976.
56. AM General Corporation, "A Study of Wheelchair Access to the Current Transit Bus Design," Contract DOT-UT-60002, April 1977.
57. D. Orne, et al, "Design, Test and Development of a Wheelchair Restraint System for Use on Buses," Twentieth Stapp Car Crash Conference, 1976.
58. J.A. Mateyka, "Safety Considerations in Design of New Transit Bus Seats," Eighteenth Stapp Car Crash Conference, 1974.
59. Virginia Polytechnic Institute, "Structure Verification of Bus Passenger Seat," Report No. PB-221258, June 1973.
60. Minicars, Inc., Ongoing Test Program at Minicars, Inc. for Caltrans under an UMTA Grant, Contract 64383.
61. M.J. Rider, et al., "Use of Wheelchairs as Vehicle Seats: Current Practice and Recommendations," Texas A&M University, 1978.

62. University of New Mexico, an NHTSA program to "Evaluate Retrofit Padding for FMVSS 222 Seats," report in print.
63. ASL Engineering, Inc., "Identification of Superior Energy Absorbing Materials for School Bus Interiors," Contract DOT-HS-7-01664, Final Report, July 1979.
64. Visit to The Bus Company of Santa Barbara, California.
65. Visit with T. Martin and G. Larsen of Metropolitan Transit District of Santa Barbara, California.
66. "U.S. Statistical Abstract," 1975, published by the Bureau of Census.
67. UMTA, "Handicapped and Elderly Vertical Movement Assessment Study," Report UMTA-MA-06-0047-75-1, February 1976.
68. HSRI Research Review, "Physical Measurements of U.S. Infants, Children and Teenagers," Volume 7, May-June 1977.
69. R.G. Snyder, et al, "Anthropometry of U.S. Infants and Children," University of Michigan, Highway Safety Research Institute, 1975.
70. Department of Transportation, National Highway Traffic Safety Administration, "Pupil Transportation Safety Program Plan," Report DOT-HS-820267, May 1973.
71. Fedeal Motor Vehicle Safety Standard (FMVSS) 208, "Occupant Crash Protection in Passenger Cars, Multipurpose Passenger Vehicles, Trucks and Buses," Federal Register, Part 571; S-208-1.
72. Federal Motor Vehicle Safety Standard (FMVSS) 301, "Fuel System Integrity," Federal Register, Part 571;S-301.
73. Federal Motor Vehicle Safety Standard (FMVSS) 302, "Flammability of Interior Materials," Federal Register, Part 571; S-302.
74. UMTA, "Transbus Procurement Requirements," Department of Transportation, Urban Mass Transportation Administration, August 1978.
75. UMTA, "Advanced Design Bus Procurement Guidelines," Department of Transportation, Urban Mass Transportation Administration, October 1978.
76. Bureau of Motor Carrier Safety – Analysis of Accident Investigations 1973.
77. Same as above for 1974.
78. Same as above for 1975.
79. Same as above for 1976.
80. Siegel and Nahum, "Bus Collision Causations and Injury Patterns," SAE Report.

81. R.W. Hull and G.W. Kuebal, "Statistical Summary of School Bus Accident Data," Southwest Research Institute, San Antonio, Texas.
82. D.M. Severy, et al, "School Bus Passenger Protection," SAE Paper 670040, January 1967.
83. Fatal Accident Reporting System (FARS) data file maintained by the Department of Transportation.
84. California State Highway Patrol, "Annual School Bus Accident Reports for Years 1974-75."
85. Same as above for 1975-76.
86. Same as above for 1976-77.
87. Dynamic Science, Inc., "MDAI Accident Investigation Case NJ-4-320," hardcopy.
88. University of Michigan, "MDAI Accident Investigation Case AA-316," hardcopy.
89. University of New Mexico, "MDAI Accident Investigation Case 102," hardcopy.
90. Southwest Research Institute, "MDAI Accident Investigation Case 7519," hardcopy.
91. C.W. Gadd, "Criteria for Injury Potential," Procurement of Impact Acceleration Stress Symposium, National Academy of Sciences, National Research Council Publication 977, 1962.
92. C.W. Gadd, "Use of a Weighted Impulse Criterion for Estimating Injury Hazard," SAE Paper 660793, Tenth Stapp Car Crash Conference, 1966.
93. "Summary Report of Data from National Survey of Transportation Handicapped People," U.S. Department of Transportation, Urban Mass Transportation Administration, June 1978.

BIBLIOGRAPHY

SCHOOL AND TRANSIT BUS TRANSPORTATION

1. AM General Corporation, "A Study of Wheelchair Access to the Current Transit Bus Design," Contract DOT-UT-60002, April 1977.

2. AMF, Advanced Systems Laboratory, "Development of a Unitized School Bus," Contract DOT-NHTSA-4-A572, May 1974.

3. American Transit Association, Urban Bus Design Objectives, October 4, 1967.

4. Crain & Associates and Applied Resource Integration, Ltd., "A.C. Transit Elderly and Handicapped Planning Study-Analysis of Needs and Alternatives," September 1977.

5. California State Department of Education, Regulations and Laws Relating to Pupil Transportation in California, 1975.

6. Demeter, John, "Transportation for All the People," Transportation U.S.A., Fall 1977.

7. Department of Transportation, "Regulating and Insuring Pre-Arranged Ride Sharing," Contract DOT-OS-50240, September 1976.

8. Department of Transportation, "Mobility of People and Goods in the Urban Environment: Mobility of the Handicapped and Elderly," Contract DOT-OS-30095, April 1977.

9. Department of Transportation, National Highway Traffic Safety Administration, "Pupil Transportation Safety Program Plan," Report DOT-HS-820267, May 1973.

10. Federal Register, Code of Federal Regulations, 49 Transportation, Parts 200-999, Revised October 1, 1976.

11. Federal Register, Vol. 42, No. 239, Tuesday, December 13, 1977, "Wheelchairs for Disabled Veterans."

12. Federal Motor Vehicle Safety Standards – Passenger Cars, Ford Motor Company, Product Development.

13. Los Angeles Unified School District, "A Report on Procedures and Requirements Related to School Bus Safety, June 1976.

14. Mateyka, James A., "Safety Considerations in Design of New Transit Bus Seats," Eighteenth Stapp Car Crash Conference, 1974.

15. National Safety Council, Accidents Facts, 1968, 1972, 1973 and 1974.

16. Orne, D., et al, "Design Test and Development of a Wheelchair Restraint System for Use in Buses," Twentieth Stapp Car Crash Conference, 1976.

17. RRC International, Inc., "Small Bus Operations in the United States," Contract DOT-UM-40015, July 16, 1975.

18. RRC International, Inc., "Small Transit Bus Requirements Study Performance Specifications for Advanced Design: Small Urban Transit Bus," Report UMTA-IT-06-0074,77-6, March 1977.

19. School Bus Fleet, December-January 1975-76, April-May 1977, August-September 1977, October-Novemer 1977, December-January 1977, December-January 1978.

20. Siegal, A.W., et al, "Bus Collision and Injury Patterns."

21. Society of Automotive Engineers, "Anthropometry of U.S. Infants and Children," SP-394, Paper 750423, SAE Automotive Engineering Congress and Exposition, February 24-28, 1975.

22. Urban Mass Transportation Administration, "Handicapped and Elderly Vertical Movement Assessment Study," Report UMTA-MA-06-0047-75-1, February 1976.

23. Urban Mass Transportation Administration, Guidelines for the Design of Future Small Transit Buses and Bus Stops to Accommodate the Elderly and Handicapped," Contract DOT-UT-50006, January 1977.

24. Urban Mass Transportation Administration, "Operating Profiles and Small Bus Performance Requirements in Urban Transit Service, Contract DOT-UT-50006, December 1976.

25. Urban Mass Transportation Administration, "Safety in Urban Mass Transportation: Research Report," Report UMTA-R1-06-0005-75-3, March 1976.

26. Urban Mass Transportation Administration, "Small Transit Bus Requirements Study – General and Performance Specifications for a Small Urban Transit Bus," RRC International, Inc. Contract DOT-UT-50006, December 1976.

27. Urban Mass Transportation Administration, "Small Transit Bus Requirements Study Performance Specifications for Advanced Design: Small Urban Transit Bus," RRC International, Inc., Contract DOT-UT-50006, March 1977.

28. Urban Mass Transportation Administration, "Transportation Problems of the Transportation Handicapped," Volume 4, Crain & Associates, UMTA Report UMTA-CA-06-0092-764, August 1976.

29. Ursell, C.R., "A Study Relating to Seat Belts for Use in Buses," California Highway Patrol, March 1976.

30. U.S. Department of Commerce, Statistical Abstract of the United States, 1975, Bureau of the Census, 96th Edition.

31. University of Illinois at Chicago, "Design for the HC in Elevated Transportation Systems," Contract UMTA-IL-11-0024-75-1, January 1975.

32. University of Michigan, Highway Safety Research Institute, "The HSRI Research Review – Physical Measurements of U.S. Infants, Children and Teenagers," May-June 1977, Vol. 7, No. 8.

33. VA Standard Design and Test Criteria for Safety and Quality of Automatic Wheelchair Lift Systems for Passenger Motor Vehicles, VAPCA-77-08-3, June 28, 1977.

34. Virginia Polytechnic Institute and State University, "Structure Verification of Bus Passenger Seats," Contract DOT-HS-069-2-334, June 1973.

ACCIDENT AND CRASH PROTECTION

1. Appleby, M.R. and Navarre, R.R., "School Bus Seat Back Pads – The California Experience," Proceedings of Nineteenth Conference of the American Association for Automotive Medicine.

2. Battelle Columbus Laboratories, "Safety in Urban Mass Transportation: Research Report," Report UMTA-RI-06-0005-75-1.

3. Bindel, Bernard, Texas A & M University, "Passenger Seating Protection in Buses," Safe Journal, 1976, Vol. 6, No. 3.

4. Boulay, P.F. and Davis, S., "The School Bus Safety Improvement Program," Proceedings of 19th Conference of the American Association for Automotive Medicine.

5. Department of Transportation, National Highway Traffic Safety Administration, School Bus Safety Problems, 1972.

6. Department of Transportation, National Highway Traffic Safety Administration, School Bus Vehicle Safety Report, Publ. DOT-HS-802-511, July 1977.

7. Mateyka, Holcombe, Booz Allen Applied Research, Cause and Prevention of Onboard Accidents, October 1975.

8. National Transportation Safety Board, Special Study – Inadequate Structural Assembly of School Bus Bodies, July 29, 1970, Report NTSB-ESS-70-2.

9. Severy, Brink, and Baird, UCLA, "School Bus Passenger Protection," SAE Paper 670040, January 1967.

10. Siegal, Nahum, Runge, "Bus Collision Causation and Injury Patterns," 15th Stapp Car Crash Conference Paper 710861, 1971.

11. Stewart, Catherine, The Mitricorp., Bus Modification to Improve Safety, Comfort, and Human Reliability.

12. Ursell, C.R., California Highway Patrol, A Study Relating to Seat Belts for Use in Buses, March 1976.

STATISTICAL SOURCES

1. Bureau of Motor Carrier Safety, Department of Transportation, Publications:
   - Analysis and Summary of Accident Investigations/1968. Also 1969, 1970, 1972, 1973, 1974, 1975 and 1976.
   - 1971-72 Accidents of Class 1 Motor Carriers of Passengers. Also 1969, 1970, 1973 and 1975.

2. Bureau of Public Roads, Department of Transportation, Federal Highway Administration, Fatal and Injury Accident Rates on Federal Aid and Other Highway Systems/1967. Also 1969, 1970, 1971 and 1972 editions.

3. California Highway Patrol, 1969 Annual School Bus Accident Report. Also 1971/72, 1972/73, 1974/75 and 1975/76 editions.

4. Michigan Department of State Police, Michigan School Bus Accidents, 1969-70.

5. Hull, Roy et al. Southwest Research Institute, Statistical Summary of School Bus Accident Data, Vol. 1, July 1968.

6. National Safety Council, Accident Facts 1968 Edition, also 1972, 1973 and 1974 editions.

7. U.S. Department of Health, Education and Welfare, Motor Vehicle Accident Deaths in the United States, 1950-67.

ACCIDENT INVESTIGATIONS

1. Bureau of Motor Carrier Safety, Department of Transportation, Motor Carrier Accident Investigation Reports:

   No. 73-1, March 7, 1973. Bakersfield, Texas
   No. 75-3, May 20, Milwaukee, Wisconsin
   No. 76-3, February 16, Lake Placid, Florida
   No. 75-1, March 7, 1975, Perry, Florida
   No. 71-5, May 7, 1971, Richmond, Virginia
   No. 75-4, July 16, Battle Mountian, Nevada
   No. 74-2, March 28, 1974, South Boston, Virginia
   No. 74-1, May 11, 1974, Charleston, Missouri

2. Bureau of Motor Carrier Safety, Department of Transportation, Accident Narratives:

   Case #74-056 Case #74-124
   Case #77-009 Case #76-099
   Case 75-016 Case #75-062

3. California Highway Patrol, "Traffic Collision Report 3472-0715-9220-4884."

4. Department of Transportation, National Highway Traffic Safety Administration Accident Reports:

AA-316	IMB 055-74
CAL 72-60A	UNM 102
CAL 72-271A	RTI-33
CAL 72-291A	USC-37
CAL-71-63	USC-SB-3
CAL-74-55	SWRI 7049
CAL-74-89	SWRI 7413
CAL-74-227	SWRI 75-19
CAL-75-80	SWRI (AB) 7520
CAL-75-96	SWRI 76-5
CAL-76-2	SWRI 76-13
DTS-082-73	UC 982D
DTS-094-73	UC 1091D
DTS-107-75	UC 1274D
IU-TAC-SP-73-3	321 KVSP
IU-TAC-SP-75-6	TOR 039-72
EPM35-36-72	TOR 048-73
EPM051-73	TOR 51/52/74
EPM-52/53-74	TOR 055-74
EPM 058-74	TOR 059-75
EPM 065-75	TOR 062-75
UNB 027-72	TOR 066-75
UNB 052-74	TOR 068-76

5. Dynamic Science, Multidisciplinary Accident Investigation:

   Case N1-4-32 (Furniture Van School Bus Rollover),

   Case SL-3-12 (School Bus-Van)

   Case SL-2-9 (School Bus-Taxi Cab)

   Case SL-1-5 (School Bus-Trash Truck Brake Failure).

6. Federal Railroad Administration, Office of Safety, Railroad Accident Investigation Summary Report 20, September 7, 1972.

7. National Transportation Safety Board:

   Collision and Overturn, Rustburg, VA, March 8, 1977, NTSB-HAR-78

   Chartered Bus Crash on U.S. Route 22, July 15, 1970, NTSB-HAR-71-8.

   Truck/Bridge/Bus Collision, U.S. 60-84; Fort Sumner, New Mexico, December 26, 1972, NTSB-HAR-74-1.

   Freight Train/School Bus Collision, Congers, New York, March 24, 1972, NTSB-RER-73-1.

   School Bus/Automobile Collision and Fire, Reston, Virginia, February 23, 1972, NTSB-HAR-72-2.

UMTA Prototype Bus Fire Near Phoenix, Arizona, May 13, 1975, Report NTSB-HAR-75-8.

Siskiyou Union High School District School Bus/Auto Collision and Rollover, Ashland, Oregon, May 9, 1975, NTSB-HAR-76-1.

Jesus Ayala School Bus Run-off Roadway/Drainage Ditch Submergence, Blythe, California, January 15, 1974, NTSB-HAR-75-1.

Metropolitan Coach Corporation, Charter Bus Accident, Bethesda, Maryland, October 11, 1975, NTSB-HAR-76-6.

Student Transportation Lines, Inc., Charter Bus Climbing of Bridge Rail and Overturn Near Martinez, California, May 21, 1976, NTSB-HAR-77-2.